THE

MATERIAL UNIVERSE

BY

M. PONTON

F.R.S.E

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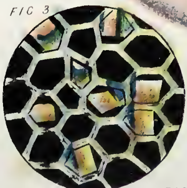
FIG 1

FIG 2

FIG 3



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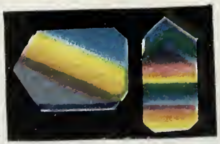

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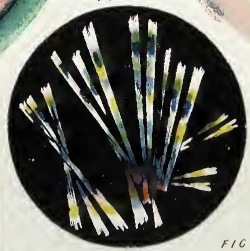

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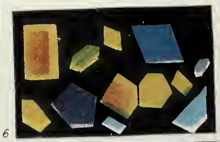


FIG 7

POLARIZATION OF LIGHT

THE

MATERIAL UNIVERSE:

Its Vastness and Durability.

BY

MUNGO PONTON, ESQ., F.R.S.E.

"Lift up your eyes on high, and behold who hath created these things, that bringeth out their host by number: he calleth them all by names, by the greatness of his might, for that he is strong in power; not one faileth."—ISA. xl. 26.

LONDON:
T. NELSON AND SONS, PATERNOSTER ROW;
EDINBURGH; AND NEW YORK.

MDCCCLXIII.

Preface.

The object of this work is to present, in a condensed form, the evidences of intelligent design in the general structure of the material universe, and of the intentions of the Creator with respect to its permanence.

The First Part is devoted to a consideration of the material masses composing the host of heaven. Their vast numbers, their immense distances, their mutual relations, their motions, the laws to which they are subject, and the admirable devices for securing the permanence of their present arrangements, are successively brought under review.

In the Second Part, the proofs of the existence of an universal ether, as the cause of luminous and other phenomena, are examined. The evidences in favour of the undulatory theory of light are sifted, and its principles are popularly explained. The beautiful phenomena, arising from the separation of light into its coloured elements, are described and illustrated.

The polarization of light, and the wonderful appearances which it evolves, the recent discoveries in reference to the spectrum as an instrument of chemical analysis, the action of light in producing photographic and analagous images, are all brought under review, and their bearing on the undulatory theory considered. Lastly, the presumed existence of an universal ether is viewed in relation to the question of the infinity of the material system in extent and duration.

The whole subject is treated in a style as popular s its nature will allow.

CLIFTON, 1863.

Contents.

PART I.

THE HOST OF HEAVEN.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV

PART II.

THE UNIVERSAL ETHER.

CHAPTER I.

CHAPTER II.

CHAPTER XII.

CHAPTER XIII.

CHAPTER XIV.

CHAPTER XV.

CHAPTER XVI.

CHAPTER XVII.

CHAPTER XVIII.

CHAPTER XIX.

PART I.

The Host of Heaven.

God! who o'er all creatures reignest,
   We desire Thy praise to swell;
For though highest, yet Thou deignest
   With the lowly heart to dwell.
When we view thy vast creation,—
   All the wonders Thou hast wrought,
We are lost in contemplation,
   They transcend our highest thought.

THE MATERIAL UNIVERSE.

PART I.

The Host of Heaven.

CHAPTER I.

"When I consider thy heavens, the work of thy fingers, the moon and the stars, which thou hast ordained; what is man, that thou art mindful of him? and the son of man, that thou visitest him?"—Ps. viii. 3, 4.

Of the multitudes who read or recite these impressive words, by far the greatest number, it is to be feared, do rarely, if ever, actually *consider* the heavens. Few in comparison are they with whom it is a *habit* to direct their attention thitherward. Of these few there are fewer still who regard the heavens as belonging to God, the work of his fingers, and the moon and the stars as having been ordained by him; while, even of these latter, they are yet a smaller residue who, from their contemplation of the heavens, draw that lesson of humility which finds expression in the exclamation, "What is man that thou art mindful of him? and the son of man that thou visitest him?"

The frequent allusions to the starry heavens, found in the sacred writings, indicate that in ancient times the religious contemplation of those marvels of creative and designing power was more habitual that in these modern days, when

the minds of even the pious and the good are so absorbed in the busy scenes of every-day life, and in the admiration of the mechanical and artistic achievements of their fellow-mortals, that they scarcely allow themselves leisure to consider the heavens, and the far higher ingenuity and skill which these display. At the present time the amount of action too greatly overweighs the amount of calm meditation; and hence the prevalence of a hasty and impatient spirit. This is not a healthy state of the public mind, because it hinders the development of purely religious sentiment, and it is accordingly the duty of those who seek to heighten and enlarge that sentiment, and to cherish a contemplative habit among their fellow-men, every now and again to urge them to consider the heavens, by directing their attention to the progress of discovery in those realms of wonder, and inviting them to the contemplation of those admirable laws, which yield such undeniable evidence of the *continuous* action of a supreme, designing, and intelligent mind.

The discoveries of modern science have led philosophers to form the following general notions of the constitution of the universe. There is supposed to exist, diffused throughout all space, an elastic fluid, of extreme fineness, and capable of having excited in it vibrations or tremors of various kinds, giving rise to the phenomena of light, electricity, &c. This fluid is called the ether. Enveloped in it, and variously disposed throughout space, are numerous globular masses, some of which have the power of exciting vibrations in the ether, while others seem to be destitute of that property. All these masses mutually attract each other; and this their mutual attraction is called the force of gravity. Those bodies which excite vibrations in the ether are called luminous, and are usually larger than those that do not; while the latter, called non-luminous, are generally placed near the former,

revolving round them in elliptical or other curvilinear orbits. Recent observations have led astronomers to suspect that, in a few instances, this general rule is reversed—the luminary revolving round the opaque body. To the class of non-luminous bodies belong the planets, including our globe; while to the class of luminaries belong the sun and the fixed stars.

These latter are disposed in various groups or clusters, those composing each group revolving round some central spot; but whether that spot be occupied by a material mass, or be merely the common centre of gravity of the whole group is unknown. Such groups or clusters are called stellar systems, and are separated from each other by enormous intervals of space. Two of the most remarkable of these clusters are represented in Plate A, figs. 1 and 5.

Our sun, with his attendant planets and comets, belongs to that stellar system, of which the greater bulk constitutes the Milky Way. This system is supposed to be of the form of a lens, and is composed of several concentric zones, in which the stars are alternately thickly studded and thinly scattered (see Plate A, fig. 3.) The constellation Pleiades is believed to occupy the central portion of the system, and the star *Alcyone*, of that constellation, to lie in or near its centre of gravity. The two portions of the Milky Way (*a i* and *e i* in the figure) are supposed to form the two outermost zones of the lens, and our sun, with his attendants, to be situated in one of the zones which are comparatively poor in stars. His position corresponds to the centre of the small white circle in the figure. Our distance from the centre of the system is estimated to be thirty-four millions of times greater than our distance from the sun; so that light, which occupies only about eight minutes in travelling from the sun to the earth, must, in coming from the stars situated near

the centre of the system, take about five hundred years to reach our globe. The sun is supposed to circulate round the centre of gravity of the system at the rate of eight miles in a second; at which rate a single revolution in his vast orbit will occupy eighteen millions of years.

All those bodies denominated fixed stars belong to this our stellar system; and the space, within which they are contained, corresponds to the small white circle in the figure, and in the centre of which the sun is supposed to be situated. The number of them visible to the naked eye amounts to only a few thousands; but the telescope reveals to us the existence of vast multitudes, lying beyond the sphere of unaided vision. The entire number of stars, composing our stellar system, is enormous—those occupying the zones interior to that in which we are placed being estimated at upwards of 100 millions, while those occupying the exterior zones must be greatly more numerous.

The distances of the fixed stars from our sun are various, but all immense. The only just criterion, by which the distance of any heavenly body from the earth can be estimated, is the amount of the yearly parallax—that is the difference of position, which the body exhibits, on being viewed at opposite seasons of the year, when the earth is at exactly opposite points of its orbit. Now the distance of the fixed stars is so great that the amount of their parallax is scarcely perceptible; and it was not till instruments and observations were brought to an extreme degree of refinement, that its amount could in any instance be ascertained. Even with the most perfect appliances, however, it is only in a very few cases, that a sensible parallax has been detected, and upon only two of the determinations can any great reliance be placed. These are, that of *Alpha Centauri*—a brilliant star in the southern hemisphere, and that of 61 *Cygni*—a

bright star in the northern. The parallax of the former is a trifle less than a second, and of the latter a trifle more than one third of that quantity. These results correspond to a distance, in the former case, of about 20 billions of miles—in the latter of about 60 billions; hence the light of the former of those stars, which is by much the nearest to our system, will take about three and a quarter years to reach the earth; while the light of the latter cannot arrive in less than ten years.

When the intelligent mind allows itself to dwell in meditation on the enormous number of the heavenly bodies, thus revealed to our ken by the help of the telescope, and on the vastness of the distances by which they are separated, it becomes utterly lost in bewilderment. On attempting to estimate those numbers, the inquirer finds them far beyond what a man could reckon, were he to be engaged in that occupation alone continuously for thousands of years. As to the distances, man's standards of measurement fail in conveying any definite idea of them to his mind. But when he reflects further, that there is ONE, who has no difficulty in reckoning these enormous hosts, "who telleth the number of the stars, and calleth them all by names,"—ONE to whom these immense distances appear but as a handbreadth, "who has meted out heaven with a span,"—then, on addressing, with his mind full of such meditations, that mighty and incomprehensible ONE, he will with greater intensity of feeling, exclaim—"What is man that thou art mindful of him? and the son of man that thou visitest him?"

CHAPTER II.

"Is not God in the height of heaven? and behold the height of the stars, how high they are!"—JOB. xxii. 12.

WHEN Eliphaz used these words, his idea of the height or distance of the stars must have been still more indefinite, than that which we are enabled to form, by the appliances of modern science. One of the most obvious methods of judging of the relative distances of the stars is by comparing their several degrees of brilliancy, although it can be trusted only to a limited extent. A very cursory glance at the starry sky, in a clear and moonless night, suffices to show even the casual observer how much they differ in this respect.

The fixed stars are classed according to an arbitrary scale, as being of the first, second, third, &c., degrees of magnitude —an unfortunate term, seeing it conveys the idea of a difference in the apparent size of those bodies; whereas there is none such—even the nearest of the fixed stars, when viewed with the most powerful telescopes, being a mere luminous point. This will be readily understood, when it is borne in mind, how minute is their parallax, which is the apparent magnitude, that the diameter of the earth's orbit would present, if removed to the distance of the star; so that unless the star had a diameter nearly equal to that of the earth's orbit, it could not exhibit any perceptible apparent magnitude; and even on this extravagant supposition, with respect to its size, the apparent diameter of the nearest fixed star would be little more than a two hundredth part of that of the moon. Doubtless in many instances the fixed stars, when viewed with a telescope, present an apparent disc; but this is only an optical

illusion, arising from the circumstance of the light emanating from a mere point. These apparent discs have always interior dark rings—an evidence that they are produced by the interference of the rays—a phenomenon having a direct dependence on the intensity of the light, and the minuteness of the point of emanation.

It would have been better had the stars been originally classed according to their degrees of brightness, rather than according to the arbitrary scale of magnitude; because it is not difficult to compare their relative brilliancy, by using two telescopes of equal power, and diminishing the aperture of that directed towards the brighter of the two stars compared, till both stars appear precisely alike; seeing the brilliancy will be in exactly inverse proportion to the apertures. An attempt has been made by Herschel to tabulate the stars upon this principle. He has found, that, while magnitude and brightness, are not exactly equivalent terms, yet there is a constant relation between the two scales; so that if the conventional magnitudes, when properly rectified, be increased by the common fraction 0·414, then will the squares of the magnitudes become inversely proportional to the numbers representing the brightness of the stars, as determined by experiment. Hence if it be assumed that the light of the stars is originally of equal intensity, the magnitudes thus augmented would pretty accurately represent the relative distances.

We are thus furnished with a method of forming an approximate idea of the distances of those stars, which exhibit no sensible parallax, by comparing their brilliancy with that of a star, whose parallax is known. Thus *Alpha Centauri* being the star, which has the greatest amount both of brightness and parallax, by comparing other stars with it, an approximation can be made to their distance, referred to that

of *Alpha Centauri* as the unit; the intensity of the light being inversely as the square of the distance.

Proceeding upon a similar principle, Struvé and Peters have constructed a table, showing the relative distances of the stars between the first and sixth degrees of magnitude—denoting the distance by the number of years in which they could be respectively traversed by light. Their estimate stands thus,—

Stars of the first magnitude average 17 years.
Stars of the second magnitude average 30 years.
Stars of the third magnitude average 45 years.
Stars of the fourth magnitude average 65 years.
Stars of the fifth magnitude average 90 years.
Stars of the sixth magnitude average 130 years.

The extreme range of distance is from about twenty billions of miles—the distance of *Alpha Centauri*—to about forty times that amount, the distance of the stars of the sixth magnitude.

The above table embraces only those stars visible to the naked eye; but the distances of the immense multitudes, discoverable by the telescope, must greatly exceed those limits. That of the most remote of those, discernible as distinct individual stars by telescopic aid, is estimated to be such as could not be traversed by light in less than 3500 years.

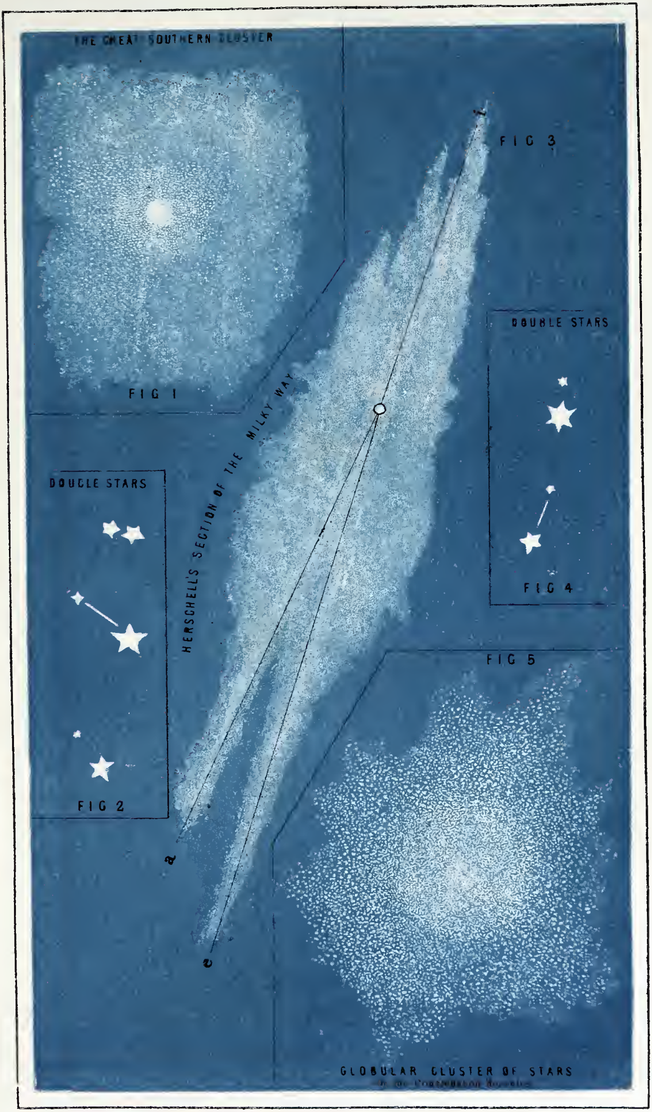
This method of estimating the distances of the stars from their degrees of brightness can be relied on, however, only within certain limits; for it proceeds on the assumption, that the stars are all nearly of equal size, and their light of equal original intensity; whereas certain observations and experiments tend to show that they vary in both respects very considerably. The parallax of a fixed star being known, its brightness may be compared with that of the sun, and the distance of both bodies being thus approximately determined, their relative magnitudes, at least their relative primary brilliancy,

may be found. Thus Wollaston ascertained the light of Sirius to be equal to that of the sun, reflected from the surface of a sphere of quicksilver, one tenth of an inch in diameter, viewed at the distance of 210 feet; and supposing half of the solar light to be lost by reflection, he thence estimated that the light of the sun is 20,000 millions of times greater than that of Sirius. Then comparing Sirius with another bright star, *Alpha Lyræ*, he found its light to be only one ninth of that of Sirius—consequently 180,000 millions of times less than that of the sun. Now the parallax of *Alpha Lyræ*, as determined by Struvé, is a little more than a quarter of a second, so that its distance from the earth is about 800,000 times greater than our distance from the sun. Were the solar orb removed to that remote distance, its light would be diminished 640,000 millions of times; but as the light of the star is only 180,000 millions of times less, it follows that its primary brilliancy is about three and a half times greater than that of the sun. Again, the parallax of Sirius is not quite double that of *Alpha Lyræ;* consequently his distance must be a little less than one half; whereas his brightness is nine times greater—corresponding to a distance of one third; whence it follows, that the original brightness of Sirius is about four and a half times that of *Alpha Lyræ*, and between fifteen and sixteen times greater than that of the sun. Such differences can be accounted for only on the supposition of a difference of magnitude; though it must be allowed that these estimates are somewhat vague.

On the other hand, that stars may vary in brightness without differing in size or distance, is evidenced by the circumstance, that certain stars alter in brilliancy from time to time. Thus the star *Omicron* in the neck of the whale, called also *Mira Ceti*, is generally invisible to the naked eye for about five months. It then gradually brightens, till it becomes equal

to a star of the second magnitude, in which state it remains for about fifteen days, when it begins to fade—declining nearly at the same rate as it previously increased. These changes are regularly periodical, and occupy 331 days, 15 hours, 7 minutes. The star named *Algol*, in the head of *Medusa*, changes from the second to the fourth degree of magnitude; its period being 2 days, 20 hours, 48 minutes. The star *Beta Lyræ* has two maxima and two minima of brightness. When brightest it is of the third magnitude, and when faintest it is between the fourth and fifth. Its period is 12 days 19 hours. These variations are probably due partly to the periodical interposition of opaque planets, revolving round those stars, and partly perhaps to changes in the stars themselves, similar to those which are exhibited by the spots on the sun. Indeed there seems little reason to doubt, that the solar orb, when viewed from a great distance, will, from the combination of both these causes, present the appearance of a variable star. If then the same star thus vary in its brilliancy from time to time, it is to be expected, that those luminaries may differ from each other in the original intensity of their illuminating power, independently of their distance, and irrespective of any difference in their size. These varieties, however, whether of magnitude or primary brilliancy, must be confined within comparatively narrow limits; and it is to difference of distance that we must look, as the great and most general cause of the observed differences in the brightness of the stars.

It has been mentioned, that the sun, with his attendant planets and comets, has been found to be revolving round the centre of the stellar system, to which he belongs. He is not, however, the only one of the self-luminous orbs composing that system, in which a similar motion has been detected. Of the others the most conspicuous are *Alpha Centauri* and



SECTION OF THE MILKY WAY & CLUSTERS OF STARS.

61 *Cygni* already mentioned. The following are the proper motions in space of the sun and these two stars in a year:—

The Sun 154 millions of miles.
Alpha Centauri 371 millions of miles.
61 Cygni 1333 millions of miles.

Thus it will be seen, that the fixed stars exhibit the same variety, with respect to their periods of motion in their vast orbits, as do the planets in their comparatively smaller revolutions round their luminous centre.

Another interesting phenomenon, establishing a general analogy between the fixed stars and our planetary system, is that of double and treble stars (see Plate A, figs. 2 and 4). Many of the heavenly bodies, which appear single to the naked eye, or even to telescopes of inferior power, are found, when viewed with more perfect instruments, to be composed of two, or even three stars in close proximity. The number of such combinations is very great—between five and six thousand having been already discovered. In some instances this proximity is only apparent, and arises from the stars lying in the same line of vision; while the one may be, in reality, a great distance behind the other; but in numerous cases, a distinct physical connection, subsisting between the bodies, has been traced. Some of these double stars exhibit a proper motion in the heavens, like those above mentioned; and they are found to accompany each other, in this motion —thus proving that they are physically connected. In other cases it has been clearly ascertained, that one of the two stars revolves round the other, while in some few instances even the periods of revolution, and the elliptical form of the orbits have been determined. Some double stars also have been observed, which appear to be both in motion round a common centre of gravity.

Thus it appears that a more intimate acquaintance with

the heavenly bodies shows us, that not only is the general height or distance of the stars enormous, but that they vary exceedingly in this particular, and not in this particular merely, but in several others; although, to the casual observer and the unaided eye, they seem to differ in brightness alone.

CHAPTER III.

"Lift up your eyes on high, and behold who hath created these, that bringeth out their host by number."—ISAIAH xl. 26.

WHEN a man of observing mind obeys this command, by lifting up his eyes on high, after sunset, in the absence of the moon, he cannot fail to be struck with the beauty of the appeal, "Who hath created these, who bringeth out their host by number," for he sees their host thus actually brought out by number, the stars coming into his field of view in great companies at a time, until a large portion of the heavens becomes, as it were, powdered with the fine star-dust of the Milky Way. It is not, however, until he avails himself of instrumental aid, and that of the most powerful kind, that he perceives how true it is that the hosts of heaven are brought out, not singly, but by legions at a time.

An attempt has already been made to convey a general idea of the nature and structure of the stellar system, to which the sun with his attendants belongs, and a faint conception of its vast magnitude. Did this stupendous system constitute the whole of the material universe, it would command our highest admiration; but when we are informed that it is only one out of many similar, the mind loses itself in the contemplation.

When a powerful telescope is turned to particular quarters of the heavens, there come into view certain masses of light, resembling a faintly illuminated vapour, which have been termed *nebulæ*, from their likeness to a filmy cloud. These were at one time regarded as the diffused materials of suns, or planetary systems, not yet fully formed. Instruments of

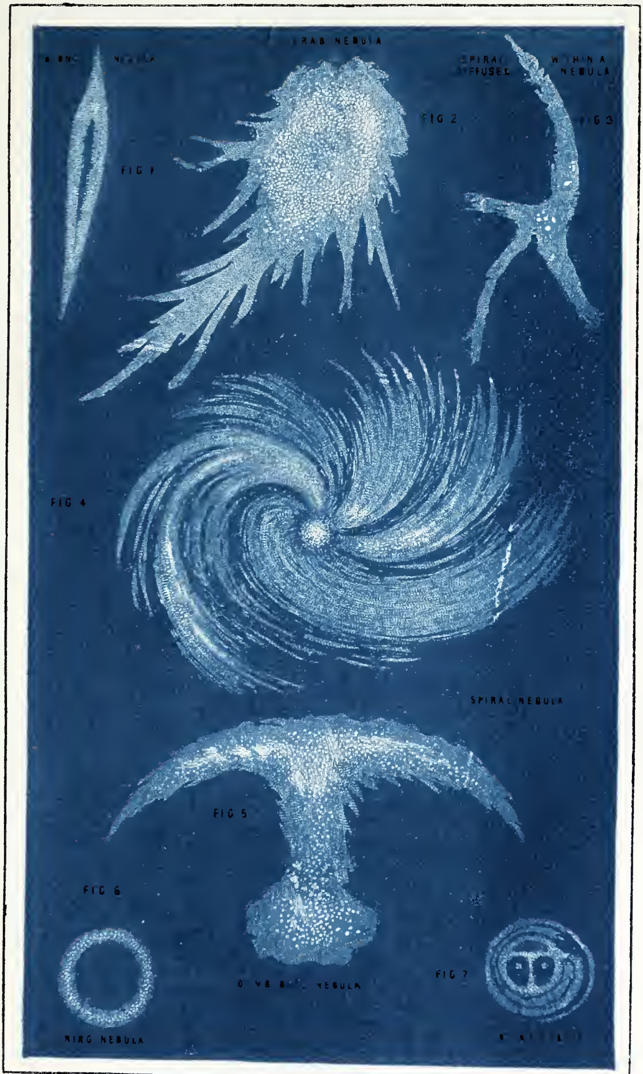
higher perfection, however, have disclosed the true nature of those remarkable objects, and shown that they are vast assemblages of stars, placed at immeasurable distances from the stellar system, to which we belong. Even those objects called nebular stars, and which were once thought to be planetary systems in progress of formation, have now been ascertained to be true nebulæ, only at still more remote distances than the larger nebular masses, and to consist of myriads of stars arranged in the form of a ring. Most of the nebulæ and nebular stars must accordingly now be regarded as distinct stellar systems, similar to that in which our sun is situated, but differing from it, as respects the mode of arrangement of the component stars. Some have them disposed in rings, some in spirals, and others in various figures more or less regular, and probably modified in their appearance by the point of sight from which they are viewed. There are indeed certain nebular masses, especially those known as the Magellanic clouds, in the southern hemisphere, which present phenomena so peculiar as to render their nature still doubtful; and we must be content to wait till instruments of superior power be brought to bear upon them before we can pronounce them to be stellar systems like those which have been already resolved into stars.

Sir John Herschell regards the Magellanic clouds as an assemblage of stars, clusters of stars, and nebulæ of various degrees of resolvability, all in close *apparent* proximity.

The telescopic appearance presented by some of the most remarkable of the nebulæ is shown in Plate B. The irregular aspect which some of these exhibit is probably due partly to the particular direction in which they are viewed, and partly to the instrument failing to penetrate to the utmost depths of the nebulous mass.

The three most regular forms under which the nebulæ

Plate B.



VARIOUS FORMS OF NEBULAE

present themselves, namely, the spiral, the annular, and the globose, have by some astronomers been conjectured to be merely three different phases of change, to which these nebulæ are subject, in long cycles of ages. In virtue of the forces by which their motions are regulated, the stars composing any nebula will all revolve round their common centre of gravity. Were this last a fixed point, the figure of the nebula would never alter, but owing to the arrangement of the stars among themselves, their common centre of gravity may be perpetually changing its position, in such a manner as to produce a secular alteration in the nature of the path, described by each of the component stars. Thus a system, which has assumed a globose form, if its centre of gravity do not coincide with the centre of the figure, may gradually pass into the spiral form. In like manner the spiral may pass into the annular, and the annular relapse into the globose, and so on without end. Hence, although we cannot see any one nebula pass through these different changes, yet, by viewing different nebulæ, in various stages of this secular progress, we may infer that each nebula may in turn present one or other of those phases. There is nothing, however, in the appearance of the nebulae to warrant the conclusion that the bodies composing them are under the influence of forces differing in kind from those which regulate the motions of our own planetary system.

These nebular stellar systems appear to be separated from each other by prodigious intervals of space ; and their distance from our system must be such as to baffle conception. Of this we have one proof, in the extreme faintness of the light which they transmit to us, and another in the great apparent proximity of the individual stars composing them, which is such as to render necessary the aid of the most powerful and perfectly defining instruments to bring their

separate outlines into view. This point may be illustrated in a very simple way. Let a sheet of black paper be pierced with numerous fine needle-holes, very close to each other, and then let a sheet of tissue paper be placed behind it. Let this paper be set before a lantern in a dark place, so that no light reaches the eye except what passes through the holes in the black paper. So long as the distance of the lantern is moderate, not exceeding 30 or 40 feet, the holes will continue distinctly visible, as minute luminous points. But remove the lantern with the perforated paper to upwards of a hundred feet, and then nothing will be seen but a faint luminous haze resembling a nebula. View it now through an opera glass, and the holes will again become visible, as distinct luminous points. But the lantern and paper might be so far removed that even the opera glass would show only a faint luminous haze, and it would require a telescope of higher power and fine definition to bring the separate points into view.

To reverse the experiment, take a portion of phosphorescent sea-water in a phial, and on its being slightly agitated in a dark place, it will present to the naked eye the same species of diffuse luminosity as that exhibited by the nebulæ seen through a telescope of moderate power. Remove a drop of the phosphorescent water and place it under a powerful and well-defining microscope. The nebulous light will now be resolved into a multitude of distinct luminous points, each of which is a separate individual organism, capable of generating luminous tremors.

A series of experiments of the first kind might enable us to form some sort of judgment of the distance of the nebulæ from our globe, as compared with the mutual proximity of their component stars. For, supposing the mutual distances of these to be on a scale somewhat similar to that of the

distances between the component members of our stellar system, the degree to which these mutual distances are apparently reduced might convey some notion of the distance of the whole assemblage from the observer. Thus, supposing the needle-holes to be on an average one twentieth of an inch apart, and that it requires a distance of a hundred feet to make the appearance nebulous to the naked eye, we should thence judge, that in a nebula easily resolvable, the distance of the mass might be about 24,000 times the average mutual distances of the component stars.

Apart from such a method of judging however, these two circumstances—the extreme faintness of the light of the nebulae and the great apparent proximity of the component stars—indicate, that the distance of the nebulae must be so great, that their light cannot travel to us in less than several myriads, or even some millions of years.

With regard to the number of these stellar systems, again, several thousands have been discovered, and many more may yet be detected by the explorations of astronomers.

Thus we of modern days are privileged to perceive in a far higher sense, than was ever contemplated by the Hebrew prophet, that the Creator of the hosts of heaven bringeth them out by number.*

* The scientific world has been recently startled by the announcement that astronomers can no longer trace a small nebula in the constellation Taurus, first discovered in 1852. In its immediate neighbourhood was a variable star, which has, since the nebula was last seen, dwindled from the tenth to the twelfth magnitude. Mr. Hind conjectures that the disappearance of this nebula, and the waning of this star, may be caused by the intervention of some opaque body. Or, as an alternative, he supposes the nebula to consist of a group of planets lighted by the star, and the apparent extinction of the nebula to be due to a change of its position in relation to the star. The waning of the latter may be connected with this change, and may arise from the planetary nebula becoming interposed between us and the star, whose fading brightness may thus be of the nature of a partial eclipse. We must, however, wait for several years to ascertain if this nebula re-appear, before any judgment can be formed respecting the nature of this singular and unexpected phenomenon.

CHAPTER IV.

"The heavens declare the glory of God."—Ps. xix. 1.

True it is, that the heavens declare the glory of God, but true also, that the great mass of mankind are too dull of hearing to understand the glory which these proclaim. Men are in general so much engrossed with their worldly pursuits, that they rarely raise their eyes heavenward; and if they do now and then look toward the sky, the greater number gaze on its shining hosts merely as a beautiful spectacle. They see nothing but a vast dome studded with bright spots irregularly disposed; and while they may haply think within themselves, that He must doubtless be a great and powerful Being who formed so large a dome, and lighted it with so many lamps, yet their wonder and admiration are too often no more exalted than is the childish pleasure with which they would view a large flight of sky-rockets; nay, were these variously and beautifully coloured, the multitude would regard the rockets as the finer spectacle of the two. They would throng to gaze upon it, and would greet it with shouts of admiration and delight; whereas they view the starry heavens with a cold and indifferent eye.

It requires a close study and unwearied observation of the heavenly bodies, to enable the human mind fully to appreciate the manner and degree in which they manifest the divine glory. A contemplation of the vastness of the scale on which the universe is constructed, tends to enlarge our views of the way in which "the heavens declare the glory of God," by manifesting his omnipresence and boundless power. But if we would penetrate more fully into the manner in which

they exhibit His intelligence, the most glorious attribute of the one omnipresent Mind, we must turn our attention more especially to those beautifully simple laws which regulate the motions of the bodies composing the planetary system, and to those singularly skilful devices by which the perpetuity of that system is maintained.

The movements of the heavenly bodies, including those of the earth, are the result of the combined operation of two forces, acting at right angles to each other. 1. The force of gravity—an attraction which all bodies, in proportion to their masses, exert on all other bodies. It decreases as the square of the mutual distance between the bodies increases; that is, when the distance is doubled the attraction is reduced to a fourth, when the distance is trebled the attraction is reduced to a ninth, and so on. The second force is called the centrifugal; because, when bodies are revolving round a centre, it manifests itself in a tendency to fly from that centre. This force acts in a direction perpendicular to that in which gravity is exerted. The term centrifugal is, therefore, not strictly accurate, because it conveys the idea of a force acting directly from the centre; the more proper name is tangential, because it acts in the direction of the tangent to a circle. Our ignorance of any physical cause for this force, in the case of the heavenly bodies, leads us to attribute it to the mere volition of the Deity. These two forces—the centripetal force of gravity, and the tangential force—exactly countervail each other; and, in virtue of their joint operation, bodies may move in any one of the four curves known as the conic sections—namely, the circle, the ellipse, the parabola, and the hyperbola. At present, the planets are travelling round the sun in elliptical orbits, differing but slightly from the circle, while the comets are generally moving either in much more elongated

ellipses, or else in one of the other two curves. In an elliptical orbit, the sun occupies not the centre, but one of the foci of the ellipse.

From the combined effect of the tangential and gravitating forces, it follows that all bodies, revolving on an axis, and possessing a certain amount of mobility in their particles, assume the form of an oblate spheroid, like an orange, flattened at the poles and protruding at the equator,—this form being one of equilibrium, and there being only one such which will, in each particular case, satisfy the whole conditions. The sun and the planets all revolve on an axis, and all possess this spheroidal form; but the tangential and gravitating forces differing in each body, the precise form of equilibrium differs also—some being more, others less flattened at the poles. Now, it is a mathematical result of this form that the gravitating force of a body of this shape, on another beyond it, is exerted in a line which does not pass through the exact centre of the two bodies. Partly from this cause, and partly from the mutual action which the bodies composing the planetary system exert on each other, arise a variety of slight and complex motions, which, in order to secure the permanence of the system, require to be adjusted with the utmost nicety and skill.

There are five particulars in which the permanence of the planetary system is involved,—1. The relation of the planets to the sun; 2. The size and form of the planetary orbits; 3. The positions of the plains in which those orbits lie; 4. The mutual relations of the periods in which the planets revolve in their orbits; and, 5. The relations of the primary planets having satellites, to those attendant bodies.

With respect to the relations subsisting between the planets and the sun, the most striking provision for securing their permanence is the immense mass of the solar orb, which

exceeds that of all the planets put together; so that, were all the latter arranged in a straight line, close to the sun and to each other, the centre of gravity would not lie beyond the solar surface.

The spheroidal form of the sun, in virtue of which the centres of the planetary orbits do not pass through the centre of that luminary, but perform a small revolution round it, is a second element contributing to the stability of the general equilibrium, because it tends to equalize the motion of the planets on the central orb. This equalization is further secured by the distribution of the planets, which is such as to prevent an uncompensated excess of action in any one direction. Subordinate to these relations is a remarkable connection between the periods of revolution of the planets, and their distances from the sun, which is such that the planets always describe equal areas in equal times, and that the squares of their periods are to each other, as the cubes of their distances from the central luminary.

There is yet another apparent law, which, to a certain extent, regulates the relative distances of the planets from the sun. If we take the series 0, 3, 6, 12, 24, &c., where 2 is a constant multiplier, and add to each the square of 2, we shall obtain a series, 4, 7, 10, 16, 28, &c., which represents the relative distances of the planets from the central orb. To this law, however, there are two remarkable exceptions. There is an apparent vacant space between Mars and Jupiter; nevertheless, although no one planet is found in this place to satisfy the law, there is a group of very small planets, which circulate in orbits having a common centre of intersection, corresponding to the distance at which the orbit of a single planet ought to be placed, in order to fufil the law. The other exception is in the case of the newly discovered planet Neptune, whose distance is considerably less remote than that which

this law would assign to it. It may therefore be inferred, that the above coincidence of numbers is rather a fortuitous circumstance than an indication of a true law of nature.

The alleged discovery by M. Lescarbault, a French amateur, of a considerable planet situated between Mercury and the sun, for which the name Vulcan has been proposed, has not as yet been confirmed by the subsequent observations of any practical astronomer. On the contrary, M. Liais, of Rio Janeiro, avers that he was observing the sun's disc at the moment of the alleged discovery, but saw nothing of the supposed planet. He imagines the body seen by M. Lescarbault to have been a meteor passing between his telescope and the sun, at no great distance from the earth. Belief in the existence of this new planet must therefore be for the present suspended.

The above mentioned fact of the space between Mars and Jupiter being occupied by a group of small planets, instead of a single large one, led astronomers at one time to imagine those small bodies to be the fragments of a single large planet which had exploded. Leverrier, however, has recently shewn this hypothesis to be untenable, being inconsistent with the great inclination of the orbit of Pallas—a conspicuous member of the group. He, therefore, supposes these small orbs to have been formed like the other planets, and by the operation of the same general laws.

Leverrier has further shown that these planets may, by their united action, exert on the earth and Mars a small disturbing force, not yet determined. He points out that, were the perihelions of the entire group equally distributed over the zodiac, the action of the one half might compensate that of the other. But these perihelion points in the case of twenty members of the group, lie on one side of the zodiac; so that their action is not compensated by that of the other six.

He further shows that were the united masses of these planets equal to that of the earth, their disturbing force would alter the position of the perihelion point of Mars by eleven seconds in a century. But, as the possible error, in the determination of the position of this point, does not amount to above a fourth of this quantity, it follows that the disturbing influence of the small planets cannot exceed that which would be produced by a single planet, having one-fourth of the mass of the earth.

The same astronomer has recently broached a further speculation, based on certain minute discrepancies between the observed and calculated motions of the four principal planets nearest the sun. According to his view, there intervenes, between the sun and Mercury, a ring composed of numerous small meteoric bodies. A second similar ring is interposed between Venus and the earth,—nearer, however, to the latter body, and causing the phenomenon called the zodiacal light. A third ring lies between Mars and Jupiter, being composed partly of the small planets discovered in that region, and partly of more minute bodies. He estimates the mass of the first ring to be nearly equal to that of Mercury; of the second to be nearly a tenth of that of the earth; and of the third to be nearly a third of the earth's mass.

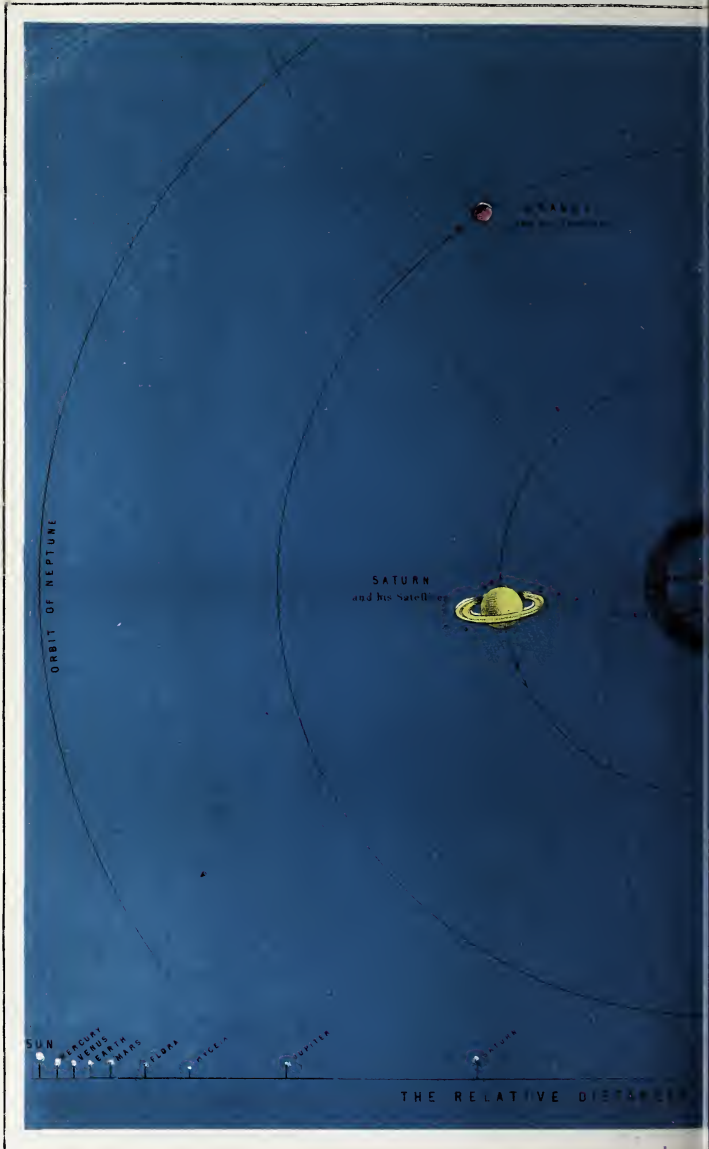
A general idea of the comparative sizes of the planetary orbits may be obtained from a simple inspection of Plate C, in which the whole system is represented, as in reference to the centre of the sun, which is regarded as a mere point. The relative distances are also laid down at the foot of the plate.

CHAPTER V.

"The Lord by wisdom hath founded the earth, by understanding hath he established the heavens."—Prov. iii. 19.

It has been shown in what manner the mutual relations, subsisting between the sun and the planets, tend to secure the permanence of the solar system. But the amount of understanding displayed by the Creator in the establishment of the heavens, is brought still more prominently into view by some of the other delicate adjustments, designed for the purpose of securing stability. Conspicuous among these are the size and disposition of the planetary orbits.

Neither the size nor the form of the orbits is unchangeably fixed, but both of these elements vary within certain prescribed limits; so that the size and form possessed at any given moment, return at stated but long intervals of time—thus giving rise to a constant mean. At present, the orbits are all more or less elliptical, but differing very slightly from a circle. Towards that form, however, they all gradually approach; each orbit will, in its own time, very nearly, but not quite, attain to it; and, immediately on reaching its smallest limit of ellipticity, it will begin slowly to elongate, and become more and more eccentric. After acquiring a certain definite amount of eccentricity, it will again change, returning towards the lower limit, and so on for ever. In the case of the earth, the orbit is at present slowly approaching the smaller limit of eccentricity, which it will attain in about 23,980 years, when it will gradually return into a more elongated curve; but several millions of years must elapse ere it gain its utmost amount of ellipticity, and recom-


ORBIT OF NEPTUNE
SATURN
SUN
VENUS
EARTH
MARS
FLORA
JUPITER
THE RELATIVE

THE SOL


NEPTUNE
and his Satellite
ORBIT OF THE COMET OF 1811
THE PLANETS FROM THE SUN

SYSTEM.

mence its approach towards the more circular form. This change of form is accomplished by an alteration of the size of the lesser axis only of the ellipse,—the greater axis remaining always of the same magnitude, or at least varying within very narrow limits, and within a comparatively short period. Were this alteration in the magnitude of the lesser axis to proceed too far in one direction, derangement of the system would ensue; but this is prevented by a peculiar relation between the major axis, the mass of each planet, and the form of its orbit, such that, while the mass and the major axis remain the same, the alterations of the minor axis must be confined within certain limits, and must oscillate between its two extremes.

Were this change in the form of the orbit, to be accomplished always in one position of the greater axis, a derangement of the system might take place; but this is obviated by a continuous revolution of the greater axis round the centre of the orbit, which last again is continually performing a small revolution round the centre of the sun. This revolution of the greater axis of the orbit proceeds in the same direction as that in which the planet travels, and in the case of the earth is performed in about 111,000 years, the period varying in each planet.

From these arrangements it follows, that there is a certain mean amount, which neither the distances of the planets from the sun, nor the velocities of their motion ever transgress; although both of these elements vary together from moment to moment. Hence arises a most important result, as respects the permanence both of the system itself, and of our standard measure of time—the sidereal year, whose length, in consequence of this mean, remains invariably the same.

With respect to the positions of the orbits, again, these also vary within certain prescribed limits. The plains in

which they lie are but slightly inclined to each other; and the amount of inclination is continually oscillating between a certain small limit and perfect coincidence. Were it to increase beyond the prescribed amount, derangement would ensue; but this fatality is prevented by a relation subsisting between the mass of each planet, the major axis of its orbit, and its inclination to the plain of general coincidence, which is such as to render a departure from that plain, beyond a certain narrow limit, impossible; so that, on this limit being attained, each orbit returning deviates in the opposite direction. This plain of general coincidence passes through the centre of gravity of the solar system; and were the plains of the orbits of all the planets to coincide with it, and were the mass of each planet multiplied into the area which it would describe in a given time, then would the sum of such products be the greatest possible. Were the change in the inclination of the orbits to this plain of general coincidence always to take place in one position of the respective orbits, there might arise some uncompensated influences; but this is provided against by the revolution of the major axis of each planetary orbit.

This combination of the oscillatory and gyratory motions involves another revolution. So long as the plains of the orbits are inclined to the plain of general coincidence, they mutually intersect that plain and each other. These points of intersections are called nodes. Lines joining the opposite nodes all pass through the centre of the sun, and at present radiate from it in various directions. But the whole of the nodes are revolving in a course opposite to that in which the planets travel; and after accomplishing their revolutions (which they do in long periods, embracing thousands of years), they return to their primitive positions.

Thus it will be perceived, that wherever continuous motion is compatible with the conservation of the system or is need-

ful to it, revolution prevails; but wherever a reciprocating motion is necessary to the permanence of the planetary arrangements, oscillation is introduced. By virtue of these revolutions and oscillations, a continual change is taking place in the disposition of the planetary orbits; but a time will arrive, after the lapse of several millions of years, when the arrangement, subsisting at the present or at any given moment, will return; and then the whole planetary system will have gone through an entire circuit of change. By that time, however, the system itself will, in virtue of the revolution of the sun round the centre of gravity of the milky way, be found in a very different part of absolute space from what it is at present; so that the recurrence of the same disposition of the planetary system will not coincide with the same relations of that system to the rest of the universe.

To this class of phenomena belongs also the variation of the obliquity of the earth's equator to the plain of its orbit, which last coincides with the ecliptic, or apparent path of the sun traced on the surface of the globe. On this obliquity depend our seasons. Its present amount is about $23\frac{1}{4}$ degrees, but in consequence of the action of the other planets, (chiefly of Jupiter and Venus), on the earth, it does not remain constant, but varies about half a second annually. The observed variation is less than it would be, were it caused by the action of the planets alone—the diminution being due to a slight displacement of the earth's equator, caused by the action of the sun and moon, to be presently explained. Were this change in the obliquity of the ecliptic ever to go too far in one direction, our seasons would be altogether deranged. On the one hand, the equator would be brought to coincide with the ecliptic, and then all variety of season would come to an end. On the other hand, were the equator to become perpendicular to the ecliptic, the variations of season

would become too great. Now, by a nice adjustment of the forces, both of these extremes are prevented; and while the variation itself is a necessary result of the planetary attractions, these are balanced in such a manner, that it can never exceed in amount about a degree and a half, on either side of its mean state; so that a just medium is preserved, and the recurrence of summer and winter, spring and autumn, is secured for ever.

As regards the periods of time, in which the planetary revolutions are performed, there are certain relations of those times, which would have introduced a tendency to destruction, and against these accordingly, the system is jealously guarded. Were the periods of two neighbouring planets exact multiples of each other, or in any other exact ratio, an uncompensated disturbance would ensue; for, at regular intervals, these planets would exert their united action in one direction. Now, a near approach to such a relation takes place in the cases of the earth and Venus, and of Jupiter and Saturn; but perfect exactness is in both instances carefully avoided, so that compensation is maintained; although, in the instance of Jupiter and Saturn, a thousand years are required for the complete balancing of their effects. In every case the periods of revolution are incommensurable with each other; consequently no uncompensated effect can ever arise.

Our admiration of these beautiful laws, and ingenious devices for maintaining the permanence of the planetary system, is enhanced by the consideration, that no other distribution of the masses, no other size of the orbits, no other arrangement of the orbitual plains, and no other relations of the periodic times to each other, or to the distances from the sun, and to the areas described, than those which actually subsist, could have secured that equilibrium of forces, by which, amid endless changes, stability is secured.

CHAPTER VI.

"He appointeth the moon for seasons."—Ps. civ. 19.

To convey a more enlarged idea of the amount of wisdom and understanding, displayed by the Deity in the establishment of the heavens, attention has been called to the very remarkable laws, by which the planetary motions are regulated, and the skilful devices by which the permanence of the heavenly mechanism is maintained.

Beautiful, however, as are those laws, and wonderful as are those devices, they are perhaps excelled in delicate ingenuity, by what is exhibited in the relations, subsisting between the primary planets possessing satellites, and these their attendant orbs.

In the case of the earth and its moon, in consequence of the periodical change in the form of the earth's orbit, and the consequent variation in its distance from the sun, the moon is alternately brought more under the influence of the one or other of these bodies. While the eccentricity of the earth's orbit is diminishing, the average effect of the sun's attraction upon the moon is continually decreasing, and she falls more and more under the attraction of the earth. Hence her orbit becomes smaller and her motion is quickened. Were this change to go too far, the moon would ultimately fall into the earth. This fatality, however, will be prevented, by the return of the earth's orbit to a more elongated form, when our planet's influence over the moon will diminish, and that of the sun will proportionally increase. Then she will gradually recede from the earth, and her motion will become slower. Were the change to proceed too far in that direction,

she would fly off from our globe altogether; but that accident is provided against by the return of the earth's orbit to a more circular form.

Similar effects take place in the satellites of the other primary planets, but to a smaller extent, owing to the greater mass of the latter, and their more remote distance from the sun.

By reason of the earth's protuberance at the equator, and the action of the sun and moon, but principally of the latter, on that protuberance, the earth's equator is made to sway to and fro—thus causing its axis to describe in space a curve resembling a double fluted cone, having elliptical bases, with certain small undulations on their edges—the point of each cone being in the earth's centre. Hence each pole of the earth describes in the heavens an elliptical orbit with a wavy outline.

The centre of this ellipse is the pole of the ecliptic, or path of the earth's orbit; and the distance, between the pole of the globe and this centre of motion, is about 23° 27′ 32″. This quantity corresponds to the obliquity of the ecliptic, and is subject to the same secular variations. In consequence of this motion of the earth's pole, the point in the starry heavens to which it is directed is continually but very slowly changing; so that the most conspicuous stars, lying near the outline of its elliptical path, come to be regarded in succession as the pole-star. The earth's pole was, at the date of the earliest catalogues of stars, 12° from the present pole-star—Alpha of Ursa Minor. Its distance is now only about 1° 26′, and it will some time hence be within half a degree; after which the earth's pole will begin to depart from that star. About 4000 years ago, the pole-star was Alpha Draconis; and it is remarkable, in a chronological point of view, that the oblique passage on the northern face of the Egyptian pyramids, leading down to

the central chamber, is in most instances directed towards that star. About 5500 years hence the pole-star will be Alderamin or Alpha Cephei, and about 12,000 years hence it will be Vega or Alpha Lyræ, which is situated at nearly the opposite point of the ellipse from the present pole-star. The direction in which the earth's pole performs its revolution, is contrary to that in which the earth moves in its orbit.

In consequence of this revolution of the terrestial pole, the equinoctial points, or those at which the earth's equator cuts the ecliptic, are continually moving backwards upon the latter, by reason of the oscillation of the equator. Hence in each succeeding year the equinox happens earlier than in the previous year, by upwards of twenty minutes—that is earlier with reference to the time, at which any particular fixed star lying near the ecliptic arrives at the meridian. This phenomenon is termed the precession of the equinoxes; and in consequence of it the longitude of all the fixed stars, or their distance from the vernal equinox on the circle of the ecliptic, is continually increased.

The revolution of the earth's pole round that of the ecliptic, and consequent backward movement of the equinoctial points, will be better understood by an inspection of the annexed woodcut, containing a portion of a chart of the constellations. Here N represents the present position of the earth's north pole in Ursa Minor; and the large circle described around N represents the present position of the earth's equator, in reference to the ecliptic, which is represented by the larger of the two circles described round E as a centre.* The distance between E and N corresponds to the obliquity of the ecliptic. The small circle K L M N, described round E, represents the

* The pole of the ecliptic E is a fixed point in the heavens, and may be found independently of the equinoctial points, by drawing a line between Alpha Cephei and Eta Draconis, and another between Theta Cygni and Gamma of Ursa Minor. E lies in the intersection of those two lines.

elliptical orbit of the earth's pole, and P represents the present pole-star. It will be perceived that the path described by the earth's pole, passes through the constellations Ursa Minor, Cepheus, Cygnus, Lyra, Hercules, and Draco; and it will be seen how it is that the star Alpha of this last constellation was formerly the pole-star, and how Alpha Cephei and Alpha Lyræ will, in the remote future, come to be successively regarded in that light.

It will also be easily understood, how the motion of the earth's pole in the direction K L M N entails a motion of the equator, in the same direction with reference to the ecliptic, causing the equinoctial points to go backward in relation to the order of the signs of the zodiac, which are marked on the circle of the ecliptic. For example, when the earth's pole was at M, the equator would occupy the position of the large dotted circle described round that point, cutting the ecliptic in the points V′ and A′, which would then correspond to the position of the vernal and autumnal equinoxes, referred to the ecliptic and the constellations in the heavens. But since the earth's pole moved from M to N, the vernal equinox has gone back on the ecliptic to V, and the autumnal to A—the positions which they now respectively occupy.

Thus it will be perceived that the autumnal equinox was once in the constellation Libra, but is now in Virgo; while the vernal equinox was once between Aries and Taurus, but is now in Pisces.

The signs of the zodiac were originally named from the constellations, to which they correspond. But the signs being merely an artificial division of the ecliptic into twelve equal parts of 30° each, which are always reckoned from the equinoctial points, it has happened that, in consequence of the precession or backward movement of those points among

the constellations, the signs of the zodiac no longer correspond to the constellations after which they were named. The sign Libra of the zodiac now corresponds to the constellation Virgo of the heavens, the sign Aries to the constellation Pisces, and so on.

This circumstance renders it possible to conjecture the date of the invention of the zodiac. The ancients reckoned from the autumnal equinox, and not as we do from the vernal. At the date of the invention of the zodiac, the autumnal equinox must have been situated in the constellation Libra, seeing the division of the zodiac in which that equinox falls, received this name. But the equinox may have been then either in the very centre of that constellation, or at the beginning of it, near its junction with Virgo. The autumnal equinox has now receded westward into Virgo about 30° from the latter of these two points, and 45° from the former. If the equinox stood at the beginning of Libra, when the zodiac was invented, then the date would be about B.C. 280; but if it stood in the centre of Libra, the date would be about B.C. 1400. This latter is the date assigned by the French Encyclopædists to the invention of the Egyptian zodiac, and appears the more probable, seeing the zodiac seems to have been known to Anaximander B.C. 610. Thus it appears that at the period of the invention of the zodiac, the autumnal equinox was probably at A′, and the north pole at M.

The precession of the equinoxes, although principally due to the action of the sun and moon on the protuberance at the earth's equator, is complicated by that which is exerted upon it by the planets. Were it produced by the former cause alone, its amount would be greater than it really is. The diminution is produced by that action of the planets, which causes the variation in the obliquity of the ecliptic before explained, and which exerts on the equinoxes an effect con-

trary to what is produced by the sun and moon. The observed precession is the resulting difference between the effects of these two actions. Save for this circumstance, the solar year would be always of the same length, and the difference between it and the sidereal year, which constitutes the precession as measured by time, would be constant. But this action causes a minute alteration in the yearly rate of the precession, and a corresponding variation in the length of the solar year, to the extent of about half a second in a century. The precession is now in the course of being increased, and the solar year of being shortened; and they have been so from the time of the earliest recorded observations; but a time was, and will again arrive, of a reversal of this action, the precession diminishing and the solar year lengthening at the same slow rate. This variation is due to the ellipticity of the curve which the earth's pole describes round the pole of the ecliptic. Were that curve a perfect circle, the rate of the precession would be constant; or, at least, it would be subject only to the variation of short period to be presently explained.

According to the best observations, the precession for A.D. 1800 was 50″ ·2285, equivalent to 20 minutes, 22 seconds, ·9636 in time. The length of the sidereal year, or period of the sun's return to the same fixed star, being constant, and amounting to 365 days, 6 hours, 9 minutes, 9 seconds, ·6, the above precession makes the length of the solar year, or the passage of the sun from vernal equinox to vernal equinox, 365 days, 5 hours, 48 minutes, 46 seconds, ·6364, for the year A.D. 1800. For A.D. 1900 it will be about half a second shorter, and the rate of the precession will be correspondingly increased.

The *mean* yearly rate of the precession is usually estimated at 50″ ·1. This result is obtained by comparing the position

of the autumnal equinox, in relation to the bright star Spica Virginis, situated near the ecliptic, as it stood in the time of Hipparchus, with its position in A.D. 1750. At the former date, the equinox was 6° to the eastward of that star, at the latter 20° 21′ to the westward of it; so that the total motion of the equinox westward in the interval, has been 26° 21′.

The mean yearly rate of precession being assumed at 50″ ·1, the total period of a revolution of the vernal equinox round the ecliptic will be about 25,868 years, or nearly 259 centuries; but this estimate must be viewed as a mere approximation.*

It has been mathematically demonstrated, that the amount of the precession would be the same, whether the terraqueous globe be solid throughout, or a hollow spheroid, provided the outer shell be of considerable thickness.

It has been mentioned that the elliptical orbit, which the earth's pole describes round that of the ecliptic, has a wavy outline. This waviness is caused by a secular variation in the action of the sun and moon on the earth's equatorial

Astronomical authorities are somewhat discrepant, in regard to the exact amount of the precession of the equinoxes; neither can the manner, in which the mean of 50″ ·1 has been determined, be deemed quite satisfactory. There is an uncertainty as to the precise date of the observation of Hipparchus, when the autumnal equinox lay 6° eastward of Spica Virginis; and Hipparchus gives its position 150 years before his time as 8°, which would make the mean yearly precession for that period only 48″. Some authors, while giving 50″ ·1 as the mean for the period between A.D. 1750 and the observation of Hipparchus, make the date of the latter B.C. 128. But the total retrogression in the period being 26° 21′, this, divided by the interval of 1879 years, would make the mean rate of precession 50″ ·4845. To bring out the mean of 50″ ·1 the interval would have to be made 1893 years, and the date of the observation of Hipparchus B.C. 142.

Again, it is generally agreed that the rate of the precession is slowly increasing; consequently the mean rate must increase, according as we take a later date, from which to reckon the interval from the observation of Hipparchus; and this will continue until the yearly rate attain its highest limit.

Calculating from the data furnished in the Nautical Almanack, which are generally obtained from the best sources, it appears that in 1850 the autumnal equinox preceded Spica by 21° 45′ 30″ ·7801, and in 1860 by 21° 53′ 53″ ·2174. The difference, being 8′ 22″ ·4373 makes the mean yearly rate of precession for the interval 50″ ·24373. This amount shows a slight increase in the rate since 1800.

protuberance, in virtue of which the earth's axis oscillates nnder the influence of the sun's attraction to the extent of 1″ ·08, and under the influence of the moon's attraction to the extent of 16″ ·9—in all nearly 18″, in the course of 9 years and 3 months; after which a like action takes place in an opposite direction. Thus, while the earth's pole is revolving in the larger orbit before mentioned, round the pole of the ecliptic, in the long space of about 259 centuries, it is at the same time describing a succession of small curves, on either side of the circumference of the greater ellipse—the centres of those curves all lying in this circumference. The pole passes through this double curvature in about 18½ years; and the number of times, that this shorter period is contained in the longer one of about 259 centuries, gives the number of undulations on the edge of the ellipse, which is nearly 1400.

This phenomenon is termed nutation, and tends further to complicate the precession of the equinoxes—causing its amount to be alternately increased and diminished; while, on the whole, it is for the present increasing. It is hence necessary to estimate the mean rate of precession, by comparing its amount at distant intervals of time.

The nutation also affects the obliquity of the ecliptic, or the distance between the pole of the ecliptic and that of the earth—seeing the latter alternately approaches the former, and recedes from it, during each cycle of 18½ years. This variation is independent of the more gradual change of long period, which the obliquity of the ecliptic undergoes in virtue of the action of the planets, mentioned in the preceding chapter.

While the equinoctial points move backwards on the ecliptie, in the manner before described, the greater axis of the earth's orbit is travelling in an opposite direction at a much slower

rate—namely, 19′ 40″ ·8 per century, or about 11″ ·808 yearly. It accordingly performs a complete circuit among the stars in nearly 111,000 years—the earth's perihelion, or point of nearest approach to the sun, coming opposite to the same fixed star at that distant interval of time. In consequence of this motion of the perihelion, the earth, in passing from one perihelion to another, has to traverse this space of 11″ ·808 which it does in about 4 minutes, 39 seconds, ·7 of mean time. This quantity, added to the sidereal year, makes the interval between each return of the earth to its perihelion 365 days, 6 hours, 13 minutes, 49 seconds, ·3—a period termed the anomalistic year.

As the perihelion and the vernal equinox move round the ecliptic in opposite directions, the rate of their mutual approach is found by adding the above 11″ ·808 to the mean yearly precession. Hence assuming the latter at 50″ ·1 the mean yearly rate of approach would be 1′ 1″ ·908; so that the period, in which the vernal equinox would pass from perihelion to perihelion, would be about 20·984, or nearly 210 centuries. But this estimate, owing to the uncertainty of the data, is to be regarded as a mere approximation.

It thus happens that the perihelion coincides successively with the autumnal equinox, the winter solstice, the vernal equinox, and the summer solstice. At the beginning of the present century, the perihelion had passed the winter solstice, on its journey towards the vernal equinox, by about 9° 30′ 5″; so that, calculating backwards at the rate of 1′ 1″ ·908 a year, the coincidence between the perihelion and the winter solstice must have happened about the year A.D. 1248, and its coincidence with the autumnal equinox about the year B.C. 3997; but as the annual rate is only approximately accurate, these dates are also only approximately correct.

Besides the yearly seasons, there is another secular effect

produced on the distribution of temperature over the surface of the globe, by the united action of the eccentricity of the earth's orbit, the obliquity of the ecliptic, and the precession of the equinoxes. From these causes it follows, that the two poles of the earth never have exactly the same mean temperature, except when the line joining the two equinoctial points coincides in position with the greater axis of the earth's orbit —a coincidence which happens at intervals of about 10,492 years. During the intervening spaces of time, the mean temperature of the one pole exceeds that of the other; because the one enjoys a longer period of sunshine in the course of the year than its fellow; for which the greater intensity of the sun's heat, during the shorter period, is scarcely an exact compensation. Throughout the whole of the historic epoch, it is the north pole that has possessed this advantage, which attained its greatest amount about the year A.D. 1248, when the winter solstice coincided with the perihelion. But about 4000 years before the Christian era, the autumnal equinox coincided with the perihelion, and then the mean temperature of the two poles was probably equal. Henceforward, down to A.D. 1248, the excess of temperature in favour of the north pole went on increasing. Since the latter date it has begun to diminish; and about the year A.D. 6494, equilibrium will again be attained; after which the excess will begin to be in favour of the south pole, as during the previous cycle.

This interchange of temperature, at the two poles, must produce a corresponding interchange of the accumulations of ice in the circum-polar regions of the two hemispheres. At present this accumulation is much in excess in the southern hemisphere; but 105 centuries ago, it was probably as much in excess in the northern. This circumstance goes far to explain the traces of glacial action found in the British

Islands, and other northerly countries, now far removed from the regions of ice.*

Founding on these phenomena, some philosophers have striven to establish the existence of a blemish in the divine arrangements, for the distribution of temperature on the face of the globe, alledging that the transfer of ice from the one pole to the other must cause periodical deluges, sweeping alternately from north to south, and from south to north. They also attempt in this manner to explain the flood in the days of Noah. But the flaw is more likely to exist in this theory, than in the divine adjustments. Seeing the excess of mean temperature in the one pole, over that in the other,

* The question of the difference of temperature at the two poles of the earth is complicated by several considerations. The duration of sunshine at the north pole at present exceeds that at the south, by 7 days, 16 hours, 51 minutes. As either pole enjoys sunshine only half the year, this excess amounts to within a trifle of four and a quarter per cent. But on the other hand the *intensity* of the sun's heat is greater at the south pole, by reason of the greater proximity of the earth to the sun during its summer. The mean distance of the earth from the sun being reckoned 1, the distance on 21st March is 0·9968875, and on 3d July 1·016743. The mean between these two is 1·0068107. On 22d September the distance is 1·002983 and the mean between July and September is 1·009836. Hence the general mean between 21st March and 22d September is 1·0083233. The distance on 1st January is 0·983236, and the mean between 22d September and 1st January is 0·993087—that between 1st January and 21st March is 0·9900627. Hence the general mean between 22d September and 21st March is 0·9915743. Thus the average *intensity* of the solar heat, between 22d September and 21st March, is to that between 21st March and 22d September, as the square of 1·0083233 to the square of 0·9915743 or as 1·016716 to 0·98322. The difference 0·033496 is a little over three and a quarter per cent of the entire quantity. Thus estimated, the excess of sunshine at the north pole is a little under one per cent.

Two causes, however, conspire to exalt the effects of this small excess. The one is that, on heat being applied to slow conductors, a moderate temperature, acting for a longer time, is more effective than a higher temperature applied for a shorter time. The other cause is the greater amount of land in the northern than in the southern hemisphere. Land radiates heat into the atmosphere better than water does, so that the air, over a sun-lit surface of land, becomes warmer than over a sun-lit surface of water. Accordingly it appears from Dove's tables of temperature, that the mean temperature of the entire surface of the globe is greater in June than in December, although the earth is so much nearer the sun during the latter than during the former month. This excess of land will thus increase the preponderance of temperature at the north pole, in comparison with the south. It is accordingly probable that, during the glacier-period in the northern hemisphere, so well known to geologists, the amount of dry land was less there than in the southern, this exchange being due partly to subterranean agency, and partly to the shifting of the sea-level, attendant on the transfer of the ice from south to north.

increases and diminishes by slow and almost insensible degrees, the transfer of ice from the one region to the other must take place in the same slow and gradual manner. There does not appear to be any known physical law, in virtue of which the effects of the accumulating heat at the one pole, and the increasing cold at the other, could be kept under restraint for many centuries, and then be developed suddenly by the melting in a single season of the preponderance of ice at the one pole, so as to cause a flood to sweep over the earth in the direction of the other. The thawing in the one hemisphere, and the freezing in its opposite, must keep pace with each other, and with the alterations of temperature. Granting that this transfer of ice and water may be accompanied by a shifting of the sea-level, this alteration must also be quite gradual; so that no sudden deluge could arise from this cause alone.

In consequence of the peculiar motion of the earth's protuberant equator before explained, a corresponding change takes place in the plane of the moon's orbit, and in its inclination to that of the orbit of the earth. Hence the points of intersection, or *nodes* of these two planes, perform a revolution in a backward direction, and in about $18\frac{1}{2}$ years; while the point of the moon's nearest approach to the earth performs an opposite revolution in about half of that period. These phenomena are analogous to the precession of the equinoxes, and the revolution of the earth's perihelion.

Amid these changes, one element of motion remains unaltered—that of the revolution of the earth on its own axis, by which the permanence of the succession of day and night, and of the length of their combined duration, is rendered absolutely secure—a permanence indispensably necessary to the well-being of the creatures inhabitating the globe, and also to the certainty of our measures of time.

From a calculation based on the earliest recorded eclipse of the moon, B.C. 720, it has been shown, that, had the length of the sidereal day altered by one ten millionth part in the course of the 2580 years, which have since elapsed, no eclipse could then have occurred.

This remark applies only to the sidereal, not to the solar day, or the period between one apparent noon and another, which varies daily. It is the mean of all the solar days throughout the year that constitutes the civil day, which is longer than the sidereal in the proportion of 1·00273791 to 1. This difference accumulates in a year to an entire day; so that the sidereal year contains one more sidereal day than it does civil days.

With respect to the moon's rotation on her axis again, it is so adjusted to her orbit, and to the time of her revolution round the earth, as to produce an exact mean equality of period. Hence she always presents to us the same hemisphere; though in consequence of the slight variability in her orbitual motion, we alternately see a little more now of her eastern, now of her western edge.

While the relations subsisting between Jupiter and his four satellites have a general resemblance to those observed in the case of the earth and moon, there is this additional peculiarity in the adjustment of the three innermost, that 1000 periods of the first, added to 2000 periods of the third, are equal to 3000 periods of the second; also the mean sidereal longitude of the first, added to twice that of the third and lessened by thrice that of the second, is equal to two right angles, or 180°. Both of these relations may subsist without danger to the stability of the system; while their existence equally excludes the idea of their having resulted from accident, or of the system having been ever subjected to the action of any accidental, or irregular and uncompensated force.

CHAPTER VII.

"The firmament showeth His handiwork."—Ps. xix. 1.

Among the many remarkable objects in the heavenly vault, which present themselves in the field of the telescope, there is none more striking than the planet Saturn, with his system of rings and moons—none which recalls more forcibly the averment, that the firmament showeth God's handiwork. For it exhibits, in a peculiar manner, how much there is of what may be termed artistic skill, in the construction of the heavenly bodies. The difficulties involved in the formation of such a system as that of the planet Saturn, were of the most formidable and complex character; seeing that, in addition to the arrangement of eight moons, it was necessary to provide for the permanent equilibrium of the massive rings, which revolve round that singular planet. The larger diameter of the outermost of those rings is 176,000 miles, its breadth 21,000, and its thickness only about 100 miles. The space between the outermost and second ring is about 1800 miles, and the latter has a breadth of 34,000 miles, while its inner edge is distant about 20,000 miles from the surface of the planet. Both rings revolve in the same direction as that body, and in nearly the same time; and so great is the rapidity of that revolution, that the molecules on the outermost edge of the exterior ring travel at the rate of nearly 50,000 miles an hour.

Recent observations have shown that the rings of Saturn are three in number, and not two, as had been previously supposed. The third ring is interior to the other two, much less brilliant, and so transparent that the body of the planet

can be seen through it. Its proximity to the innermost of the other two rings is such as to have led astronomers at one time to conclude, that it might be rather an appendage to it, than a distinct ring—that it might perhaps be a denser portion of the atmosphere of the inner ring; for both of the originally discovered rings have been ascertained to be furnished with an atmosphere, from the circumstance of its causing so great a refraction of the solar rays, as to spread a twilight over the entire surface of both rings, by which their sides averted from the sun are rendered faintly visible. Further observations, however, have led to the detection of an interval between the second and third rings, so well defined as to be capable of measurement.

Observers have further been led to imagine, that they can trace a gradual approach of the third or innermost ring, to the surface of the planet, such as might ultimately result, in its being precipitated on the surface of the orb, or its diffusion through the planet's proper atmosphere. The analogy of similar cases, however, would rather lead to the inference, that, if such a gradual approach be really in progress, it is far more likely to be merely one of the phases of an oscillating movement, which will proceed in one direction for a certain time and then return. It is quite conceivable that as the orbit of Saturn lessens in ellipticity his mass may exert an increasing amount of attraction on the system of his rings, and that if these possess a certain amount of elasticity, they may, so long as this decrease in the ellipticity of the orbit continues, gradually approach the body of the planet. Such an approach would be more marked in the nearest and most elastic of the rings. If it be due to this cause, it will attain a maximum when the ellipticity of the orbit arrives at its minimum, and then, as the ellipticity begins again to increase, the ring

will commence receding from the planet. This alternate approach and retrocession may continue for ever, like the alternate approach and retrocession of our moon, before described.

The most recent observations and measurements, however, throw great doubt on the accuracy of those from which an approach of the innermost ring to the planet has been inferred.

Now two conditions are indispensable to the permanent equilibrium of these stupendous masses—the one, that their centre of revolution should not exactly coincide with the centre of the planet—the other, that each ring should not be of uniform thickness and density throughout, and that the thickness of the two exterior rings should not be precisely the same. The first of these conditions is secured by the oblate form of the planet, and it has been ascertained by observation, that the centres of revolution of the rings, though near the centre of the planet, do not coincide with it, but perform around it a small revolution. The existence of the second condition was more difficult of discovery; but in the course of their changes, it happens at intervals of about fifteen years, that the two rings, instead of exhibiting their flat sides to our observation, present their edges, and are seen as a mere line, crossing the disc of the planet, and projecting beyond it. By careful observation of them during this phase, it is found that, on the gradual evanescence of the two projecting extremities of the rings, the one remains visible longer than the other—sometimes the first and sometimes the second vanishing soonest. This could not happen were the thickness of both rings uniform throughout, or were the two precisely of the same thickness. Hence the second condition of equilibrium also exists; while the very near approach to equality and uniformity of thickness, is a clear indication,

that the small departure, necessary to permanence of stability, was not the result of accident.

Professor Clerk Maxwell has lately submitted certain mathematical considerations tending to show, that Saturn's rings are less likely to be continuously solid or fluid, than an aggregation of incoherent solid materials. He maintains this constitution to be better adapted, than either of the others, to secure permanent equilibrium. In evidence of his view, he adduces the remarkable circumstance, that the innermost ring, while transparent, does not refract the light of the planet passing through it, as would a continuous fluid or solid transparent substance. He thence infers that the light passes through the interstices of a loosely aggregated collection of incoherent solid masses.

An attempt has recently been made by M. Plateau of Ghent, in a memoir published in Puggendorf's Annals, to trace the formation of the rings of Saturn to the mere natural operation of the force of cohesion, in conjunction with the centrifugal force, produced by the rapid rotation of this planet on its axis. By a very ingenious experiment, he endeavoured to illustrate the mode of formation of similar rings. Having brought a mixture of alcohol and water to be nearly of the same specific gravity with that of olive oil, he cautiously introduced into the mixture a portion of the latter fluid, which straightway assumed a globular form, becoming suspended in the middle of the alcoholic mixture, and so liberated from the action of the earth's gravitation—its parts being held together simply by molecular attraction. By insinuating into the middle of the globe of oil an axle with a flat disc in its centre, he was enabled to communicate to the oil a rotatory motion. When the speed was moderate, the sphere became flattened into a spheroid; but when the rotation was accelerated beyond a certain pitch, a distinct ring was formed

round the sphere of oil, connected with it by a thin film. This film, however, could by a little management be obliterated; and M. Plateau thus enjoyed the spectacle of a spheroid rotating on its axis, with a totally distinct ring rotating round the same axis—thus presenting a striking analogy to the system of Saturn (see Plate D, fig. 1).

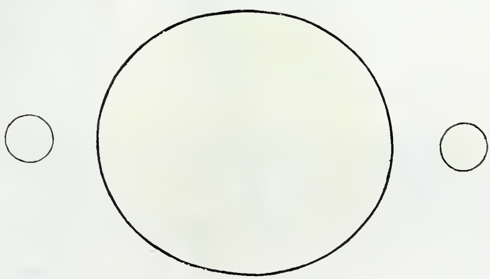
On carefully examining the description of this experiment, and probing the cause of the phenomenon, it will be found that the analogy is more apparent than real. The ring of oil differs entirely from those of Saturn. Its section is circular (see Plate D, fig. 2); whereas the rings of the planet are exceedingly flat. The origin of the ring of oil, moreover, must be very different from anything that could subsist, in the case of the rings of Saturn. The formation of the ring of oil is due mainly to the circumstance, that, when the speed of rotation is increased beyond a certain pitch, the friction between the oil and the alcoholic mixture, in which it is suspended, becomes so much increased, as sensibly to counteract the further development of the centrifugal force, at the outer surface of the oil. The consequence is, that the interior molecules of the oil acquire a disproportionally greater centrifugal force, which tends to throw outwards the more retarded portion of the mass; and thus a separation is ultimately effected between the central part of the rotating spheroid, and its equatorial portion, which then flies off in the form of a ring with a circular section. But, save for the retarding influence of the alcoholic mixture, the exterior equatorial portions of the oil would always have a higher centrifugal speed than any portion nearer the axis of the mass; consequently, in the absence of the alcoholic mixture and its frictional resistance, no ring could be formed.

There can be nothing similar to this outer resisting fluid in the case of Saturn; and it is therefore vain to cite this

PLATE D.

FIG 1

FIG 2



GLOBE AND RING OF OIL.

experiment, as tending to show, that the rings of Saturn may have been produced, by the mere natural, undirected operation of the centrifugal, gravitating and cohesive forces—that they were thrown off similarly to the ring of oil, because Saturn happened to have acquired a high amount of whirling speed—in other words. that these wonderful, admirably constructed, and nicely balanced rings were, in common with all the other planetary masses, the result of laws operating under no other guidance than that of blind chance.

Chance! what sane mind can contemplate those simple laws, those beautiful arrangements, those delicate adjustments, and attribute them to chance? As well might we regard the most ingenious chronometer, or the most powerful steam-engine as the result of an accidental assemblage of atoms. No; intelligent design pervades the whole; forecast is evident throughout; nor less manifest is the existence of a fixed intention, on the part of the intelligent and far-seeing Designer, that those wonderful arrangements should be permanent,—that "He has made a high decree that shall not lapse," that He has established them for ever and ever.

Nor does it appear possible for any reflecting mind to meditate on the wonderful mechanism of the system of Saturn, and subscribe to the opinion, expressed in a notorious work, that so magnificent a planet is fitted to be the abode only of zoophytes or reptiles, and is wholly destitute of intelligent inhabitants. How can it be imagined, that all these remarkable contrivances for the distribution of light, and for adorning the skies of Saturn, are designed for the well-being of irrational creatures only, and that there are no intelligent beings, capable of admiring their beauty, and appreciating the ingenuity they display? If there be one proof, which, more than any other, forces on the mind the conviction, that

the planets are the abodes of intelligent beings—of those "angels who excel in strength, that do God's commandments, hearkening unto the voice of his word," it is the evidence furnished by Saturn, his rings and his moons. For surely they must be beings of high intellectual power and refined taste, to whom so glorious a habitation has been assigned.

CHAPTER VIII.

"Wandering stars to which is reserved the blackness of darkness for ages."
JUDE 13.

IN this comparison of the wicked to wandering stars, for which are reserved long ages of darkness, it appears probable that the Apostle Jude had in his mind's eye, not the ordinary denizens of the starry firmament, but those singular and striking objects, the comets, which, for the most part, visit our centre of light for only a comparatively brief period, and then depart into far distant regions of space, where they must pass many long ages in nearly absolute darkness.

The attention of astronomers and of the intelligent portions of mankind in general, has been recently directed in a more than ordinary degree to these singular bodies, by the remarkable comet of 1861, and by its more splendid precursor, which excited the admiration of Europe in the autumn of 1858—rivalling in magnificence the less generally remembered, but not less beautiful visitor of 1811. The bearing of cometary phenomena on the question of the permanence of the arrangements of the universe, accordingly, obtrudes itself in a special manner at this time upon the notice of every reflecting mind.

It has been shown that the very peculiar provisions, which have been made for the evident purpose of securing the permanence of the planetary mechanism, is a strong indication of its being the intention of the divine mind, that the subsisting arrangements should endure for ever. But an objector may appeal to these wandering stars, exclaiming,—

"Ay, but the comets—those bold intruders into the plane-

tary domains, whose terrific aspect and erratic course fill with amazement and terror the ignorant and superstitious mind, may not they, in their wild career, derange some of the delicate mechanism of the heavens? Might not one of these wanderers, crossing the terrestrial orbit, impinge on the moon, and dash it against the earth; or haply striking this our globe, either plunge it into the glowing sun, or sweep it away into those distant regions of ether, dark and cold, whither itself is bound?"

Fear not. That same unerring hand, which arranged the system of Jupiter's satellites, and poised the ponderous rings of Saturn, has traced the course of each of those wanderers in the ethereal wilderness, has weighed its mass in a balance, and compassed the limits to which its vast dimensions may expand. We may be confident that their eccentric paths and their periods of revolution are so adjusted, that they can never interfere with the harmonious arrangement of the planets, and that, even if they should approach within an apparently dangerous proximity to any of the planetary orbs, their invasion would pass unattended by harm.

Of the innocuous nature of these bodies, we have a satisfactory proof in the circumstance, that one of them—the comet of Lexall traversed the system of Jupiter's satellites, without causing the smallest disturbance in the delicate adjustment of his moons. To understand how this may be, a few words of explanation will suffice.

When a comet first arrives within the range of telescopic vision, it appears like a circular fragment of illuminated cloud. As it approaches the sun, three distinct portions can be discerned. The outermost called the envelope, resembles a luminous haze; within it is the head, which is brighter and more condensed; and within that again is the nucleus, which is much smaller, brighter, and still more condensed than the

head. Of these, the nucleus is the only portion of a comet, which has any appearance of solidity; but on being viewed with telescopes of high power, it is generally found to merge so gradually into the rest of the head, that no definite boundary can be assigned to it. We must accordingly regard the substance composing the head, as merely increasing in density towards the centre, so giving rise to this semblance of a solid nucleus.

Now one of the most remarkable features of this substance is that, while capable of reflecting the solar rays to a very considerable amount, it is at the same time perfectly transparent, insomuch that the light of even the faintest stars can be seen through it—stars whose visibility would be destroyed by the slightest haze in the atmosphere. This transparency was exemplified in a striking manner by the comet of 1858, when it intervened between the observer and Arcturus, in which case the light of the fixed star, so far from being diminished, was actually augmented by the luminous material of the comet, the reflected light of the latter aiding the direct light of the fixed star in impressing the organ of sight—a phenomenon analogous to that produced by the transparency of flame. But while thus perfectly transparent, the cometary material is destitute of any refractive influence on the light of the star transmitted through it; not the slightest displacement of the rays can be detected. It is not yet a decided question, whether the perfect transparency extends to the nucleus. Some astronomers imagine that they have noticed stars to be hidden for a second or two, while the nucleus intervened; but this is denied by others, and ascribed to optical deception.

When comets draw near the sun, there is sometimes observed a dark ring separating the head from the envelope, indicating that the latter is a luminous shell suspended over

an elastic and non-luminous stratum, dividing it from the head. But this appearance is not uniform. On a nearer approach to the central luminary, a remarkable change takes place in the appearance of the stranger. The envelope begins to bulge out towards the sun, and then, as if it had acquired, or been acted upon by some new force, it begins to fold backwards in two divisions, which stream out behind the comet, and eventually unite into one curvilinear expansion, forming the beautiful appendage designated the tail. This phenomenon some philosophers attribute to a repulsive force, probably electrical, exerted by the solar atmosphere. The luminous train thus formed follows the comet in its course, until it pass its perihelion or point of nearest approach to the sun. Few comets, however, can be traced up to that point; for being bathed in the radiance of the central luminary, they cannot be distinguished by even the best defining telescopes.

On emerging from this sea of glory, comets are sometimes found to have lost their luminous train, at least that appendage has ceased to be capable of reflecting light; but that it has not been dissipated appears from the phenomena, which the comet presents after passing the perihelion. In other instances again, the tail does not attain its full development till after this passage. Prior to its disappearance in the blaze of the sunbeams, the head of the comet is frequently observed to diminish rapidly in bulk, as if a large portion of its material became so attenuated as to cease to be capable of reflecting light. On emerging again from amid the solar rays, the head begins gradually to increase in volume, as if the attenuated matter were in course of condensation, regaining, with its augmented density, the power of reflection. This phenomenon was well displayed in the comet of 1861, which was first seen in Europe after its perihelion passage; the magnitude of its head on the first night of its appearance

having been such as to arrest universal attention. As the comet recedes from the central orb, the head gradually acquires the same dimensions as it had before it began to decrease. When first seen after passing the perihelion, those comets, which have then lost their tails, are surrounded by a *coma* or luminous haze of great extent, obviously the matter of the tail, which gradually condenses until it resumes its original appearance of a luminous envelope; after which the whole body of the comet begins to shrink in volume, and it finally regains exactly the same aspect which it presented when it first came into view. In those instances, again, where the tail attains its fullest development after the perihelion passage, that appendage on reaching its maximum, begins to decrease by degrees, and finally returns to its first condition of a luminous envelope.

CHAPTER IX.

"I will show wonders in the heavens."—Joel ii. 30.

Of the many striking objects in the starry heavens, none are so calculated to excite in the human mind the sentiment of wonder as the comets; while of the curious phenomena which they present, none are so remarkable as the formation, general aspects, and final disappearance of the tail. That marvellous appendage is sometimes of prodigious dimensions, extending through a large arc of the heavens. The apparent size varies according to the climate of the place whence it is viewed, being always greatest in those genial climes, where the atmosphere is particularly clear. The actual length of the tail is sometimes very enormous. The following table shows the estimated length of the tails of six remarkable comets,—

Comet of 1680, length of tail 96 millions of miles.
Comet of 1769, length of tail 38 millions of miles.
Comet of 1811, length of tail 100 millions of miles.
Comet of 1843, length of tail 150 millions of miles.
Comet of 1858, length of tail 40 millions of miles.
Comet of 1861, length of tail 16 millions of miles.

The breadth of the tail is not correspondingly vast. The greatest breadth of that of the comet of 1811, was estimated to be fifteen millions of miles.

The tail is equally perfect in its transparency with the rest of the cometic matter; and its illumination does not proceed entirely from reflected light; for it is observed to flicker and flash in a very remarkable manner. Sometimes, also, streams of light are seen to dart out sideways from the comet, and even in front of it, giving it the appearance of having more

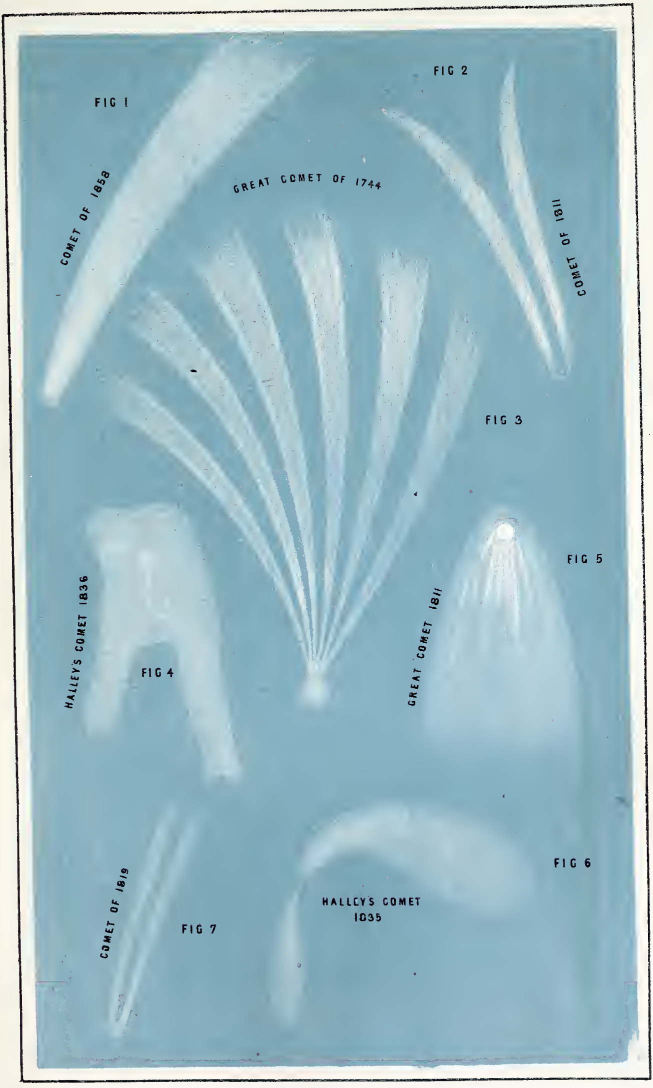


FIG 1
COMET OF 1858
FIG 2
COMET OF 1811
GREAT COMET OF 1744
FIG 3
HALLEY'S COMET 1836
FIG 4
GREAT COMET 1811
FIG 5
FIG 6
HALLEY'S COMET
1835
COMET OF 1819
FIG 7

COMETS.

than one tail. The comet of 1744 had six such streams of light emanating from it, and spreading out in the form of a fan. The comet of 1823 had two tails, one in the usual direction, and another exactly opposite, being turned towards the sun; while the comet of 1843, after having formed the usual tail, sent out a lateral one of much greater length. The telescopic aspect of the most remarkable of the comets of recent times is exhibited in Plate E.

The light of the tails of comets bears a strong resemblance to that of the Aurora Borealis, and the Zodiacal Light (see Plate F, figs. 1 and 2). In another particular, also, does it resemble those meteors, namely, in perfect transparency. It is, therefore, not improbable, that while the general glow of the tail of a comet is of the same nature as that of the zodiacal light, and caused by the reflection of the sunbeams from a highly attenuated material, the streams of light and the appearance of tails in different directions, away from the rear of the comet, may be due to the same cause as the Aurora Borealis, namely, to electrical discharges passing through a very rare medium.

The resemblance between the tails of comets and the zodiacal light is highly suggestive. The zodiacal light is a faintly shining cone, observed at certain seasons of the year when there is little twilight. North of the equator it appears in the west after sunset,—south of the equator, in the east before sunrise,—during February and March, and *vice versâ* during August and September. The light stretches along the line of the zodiac,—the base of the cone, nearly 10° broad, being in the horizon towards the sun; while, in temperate climates, the top is at a height of about 40° or 50°, near the Pleiades. In tropical climates the light is brighter, and the top of the cone can sometimes be traced to a distance of 90°, or even 100° from the sun. In December

again, north of the equator, one side is seen in the evening after sunset, and the other in the morning before sunrise. In June the same appearances present themselves south of the equator, the sides observed being reversed. At the winter solstice, immediately under the northern tropic, both summits of the cone have been seen at the same time, an hour before and an hour after midnight. This observation indicates that the limits of the meteor extend beyond the line of the earth's orbit, regarded as passing through the centre of the globe. Viewed in its integrity, the meteor seems to have the form of a doubly convex lens. Its centre may be referred to the sun, and its central plane appears nearly to coincide with that of the sun's equator.

To explain this phenomenon several theories have been broached. Some have regarded it as identical with the luminous glory seen around the sun when he is totally eclipsed, and which is believed to proceed from his outermost atmosphere. This glory is supposed to be projected upwards by an extraordinary refraction of the earth's atmosphere to form the zodiacal light. It is remarkable that, in total solar eclipses, the zodiacal light does not appear as a phenomenon distinct from the luminous glory; but this may be owing to its greater distance from the sun. Others have imagined the solar atmosphere itself to be, at his equatorial regions, compressed into a lenticular form, to stretch beyond the earth's orbit, and to present itself under the aspect of the zodiacal light. A third supposition is that this light is caused by a ring of numerous small meteors revolving round the sun, in an orbit somewhat inclined to that of the earth, and constituting the source whence our shooting stars and aerolites are derived. A fourth idea is that this supposed ring consists not of solid meteors, but of a thin filmy substance like that of the tails of comets—a view countenanced

PLATE F.

AURORA BOREALIS.

ZODIACAL LIGHT.

by the mutual resemblance which these two phenomena exhibit. A fifth notion is that the ring, while of this filmy character, surrounds not the sun, but the earth, within the orbit of the moon. A sixth theory is that the zodiacal light is due to a special action exerted on the luminiferous ether by the sun's equatorial regions, caused by his rotation on his axis, combined with his motion of translation through space. Shooting stars are in like manner attributed to the effect produced on the ether by the earth's complex motion, consisting partly of its annual revolution, and partly of its translation through space along with the sun.

None of these theories can be deemed quite unobjectionable; so that the cause both of the zodiacal light and of shooting stars and aerolites, may, in the present state of our knowledge, be regarded as very uncertain. Some shooting stars seem to be merely electrical discharges, in the higher regions of the atmosphere, passing through either highly rarefied common air, or collections of inflammable gas accumulated at those heights. Aerolites, again, have doubtless a cosmical origin.

To return to the comets, the remarkable phenomenon of the streams of light, darting from their front and sides, as well as extending a long way in their rear, seems to indicate that the rare elastic matter composing the tail, is not confined to the rearward of the comet, but completely surrounds it, and that its general invisibility, save in the direction away from the sun, is owing to its temperature being so high, that it ceases to be capable of reflecting the solar rays. Of the effects of change of temperature on the relation of gaseous bodies to light, we have a striking example in the case of nitrous acid gas; and even in the more familiar instance of watery vapour, we have a somewhat analogous phenomenon,—steam at a high temperature reflecting little or no light, while steam at a low

temperature reflects it abundantly,—a change due to the assumption of the vesicular form of vapour. It is only in those portions of these vast atmospheres, which are furthest removed from the influence of the solar heat, and which are comparatively cool, that they appear capable of reflecting the sunbeams. This circumstance further confirms the idea, that the light seen in advance of the comet, or darting out from it laterally, is more akin to that of the Aurora Borealis than to that of atmospheric reflection; but it is quite possible that these streams of light may result from the partial cooling of the attenuated material, caused either by internal changes proceeding in the comet itself, or from the unequal action of the sun, occasioned by the presence of large solar spots.

If the expanded material of the tail thus surround the comet, we should be led to infer that it assumes a very flat spheroidal form, such as would arise from a rapid rotation of the comet on its axis, but that only that region of this vast atmosphere is continuously visible, which, being furthest from the sun, is sufficiently cool to reflect his rays. The axis of rotation will probably be at right angles to a line passing through the centre of the tail and of the comet.

From the above description it is plain, that, while the volume of comets is so very enormous, their material is yet so rare, that their mass must be comparatively insignificant. Indeed, the whole phenomena presented by comets indicate that their molecules are held together by gravitation alone, without any cohesive attraction whatever. And hence it is, that these formidable-looking intruders exert no disturbing influence on the planetary orbs. The smallness of their mass, and the extreme tenuity of their substance are evidenced by their transparency and their inability to refract light. We know that the earth's atmosphere exhibits a perceptible refraction at the height of forty-eight or even

fifty miles; whence it may be inferred, that the substance of a comet is less dense than atmospheric air at that elevation. It is nearly at this height that the Aurora Borealis is supposed to play; showing us that matter of that degree of rarity, while incapable of refracting light, may yet be rendered luminous by electricity, or by reflection. At the height of forty-nine miles, the atmosphere is nearly 1600 times rarer than at the earth's surface; so that if the cometic matter be of this degree of tenuity, its weight must be very trifling and incapable of exerting any appreciable effect on such massive bodies as the planets.

Of matter possessing a similar degree of tenuity, we have an example in the exterior atmosphere of the sun, rendered visible by reflection, when the sun is wholly eclipsed.

What takes place on the formation of the tails of comets, shows how highly expansible is the material of which they are composed. It is obvious that the tail is formed by the great expansion of part of that substance, which is thrown outwards from the head. The occasional disappearance of the tail, after the comet passes the perihelion, is probably rather an optical than a physical phenomenon, and seems to arise from the matter of the tail having become so much rarefied, as to be incapable of reflecting light, until it begins again to condense; when it appears as an extended nebulous envelope, completely surrounding the comet, instead of a luminous train extending behind it,—an effect probably due in part to a change of position.

CHAPTER X.

"By his Spirit he hath garnished the heavens."—JOB xxvi. 13.

THE only point in regard to the history of comets remaining to be considered is their orbits, which are generally ellipses of a very elongated form, the sun being situated in one of the foci. A few of these bodies never travel beyond the limits of the planetary system; while others penetrate into regions much more remote, yet return punctually at their appointed season to revisit the central luminary, to which they sometimes make a very near approach. The comet of 1680 came within a distance equal to one-third, and that of 1843 within a distance equal to one-seventh of the solar diameter. So near an approach indicates an extreme degree of eccentricity in the orbit, such as to render it doubtful whether the curve described be a true ellipse, and whether the comet will ever return to the sun. This is a question which it will be difficult to decide; for, on the supposition that the orbit is an ellipse, the period of the wanderer's return must be very distant. The periods of some comets have been estimated to exceed three thousand years; but that of others is comparatively short, especially of those which keep within the limits of the planetary system.

The orbits of comets do not, like those of the principal planets, lie nearly all in one plain, but are inclined at every possible angle to the plain of the orbit of our globe. And as regards this inclination, there is evidence of a beautiful provision of wisdom and forethought. Had any of those comets which are remarkable for very long tails travelled in orbits nearly coincident with the plain of the ecliptic, Mer-

cury, Venus, and the Earth might have been enveloped in those subtle emanations; but all comets with long tails have their orbits so much inclined to that of our globe, as effectually to prevent such a catastrophe. Those comets, again, whose orbits are little inclined to the plain of the ecliptic, have not tails of sufficient length to extend to the planets.

On more than one occasion comets have passed very near the earth's orbit; and on its becoming known that they would thus skirt our path, considerable excitement has prevailed at their approach; but it has in every such instance been found that the periodic times of the comet and of the earth are so adjusted to each other, that our globe is at a different part of its orbit from that which is skirted by the comet, at the moment of its passage. The comet of 1861 had its orbit very highly inclined to the plain of the ecliptic, and its tail crossed the path of the earth within a very short period before our globe reached the same point. Some astronomers, indeed, have expressed an opinion that the tail of this comet must, about the time of its first appearance in these latitudes, have actually skirted the earth's atmosphere. But others deny the accuracy of the data on which this opinion is founded. The occurrrence is altogether improbable; for if the tail did enter the earth's atmosphere, and so become subject to the powerful gravitation of our globe, it does not appear possible that the comet should have been able to gather it up again, and carry it away. A portion of the tail must have been abstracted by the earth, and must now form a permanent addition to our atmosphere. This addition would have been rendered manifest by a general rise in the mean height of the barometer all over the face of the globe. There seems little room to doubt, that were our analysis sufficient to enable us to calculate with accuracy the periodic times of those comets, which thus approach so near the

earth's orbit, it would be found, that the difference of position above mentioned is the result of a law, by which the system is secured against all possible danger of a collision.

It is not impossible that some comets may visit another sun, besides the centre of our system, or perhaps even a great many in succession, or that they may have their orbits modified and altered by their approaching very near the planets. There is, indeed, reason to believe that occurrences of the latter kind have taken place. But such things may happen, without injury to the stability of the system; for, as already explained, the mass of a comet is so small, that it may enter into or depart from a planetary system without causing any appreciable derangement. One remarkable comet, that of Biela, was observed on its approach to its perihelion, in 1846, to separate into two, and the two bodies pursued their journey in close proximity, so long as the comet remained visible. Instances of a similar occurrence on previous occasions have been recorded.

When the mind reflects upon this and the other wonderful phenomena above described, it is led to ask within itself, what possible purpose can these remarkable bodies be designed to subserve? From the rarity of their material, from the violent changes they undergo, and the extreme alternations of heat and cold to which they are subjected, they are obviously not designed to be the abode of organic beings. If we look for any physical or mechanical end, to which they may be subservient, we search in vain. What then? May not their purpose be purely moral and metaphysical? May they not be merely ornamental, the flowers of the solar system, intended to excite the wonder and admiration of the intelligent beings, who inhabit the denser planets? Did the starry heavens always present the same aspect, the inferior orders of intelligence might be apt to regard them with in-

difference. But when a comet appears in the sky, with its long train of light, it arrests the gaze of every beholder. Even the savage cannot eye it with indifference; and the attention of the very dullest of minds is thus awakened to the contemplation of those heavens, which declare the glory of God, and that firmament which showeth his handiwork. Comets then may be regarded as a kind of celestial firework, in appearance tremendous, but in reality harmless, their purpose being merely to grace the planetary system, to display the profusion of the Creator, and the inexhaustible resources of his wisdom and skill, in devising and arranging the paths of those ornamental luminaries, in such a manner as never to interfere with the delicate adjustments he has contrived for securing the permanence and well-being of those more useful orbs, which are designed to be the abodes of organic beings.

CHAPTER XI.

"Thus saith the Lord who giveth the sun for a light by day and the ordinances of the moon and of the stars for a light by night, who divideth the sea when the waves thereof roar. The Lord of Hosts is his name. If these ordinances depart from before me, saith the Lord, then the seed of Israel also shall cease from being a nation before me for ever."—JER. xxxi. 35, 36.

OF these words, spoken by the prophet in the name of the Lord, and in obedience to his command, the object is to convey to the children of Israel a strong assurance of their permanence as a nation before him; and to make this assurance stronger, he appeals to the ordinances of the heavenly bodies, as possessing the highest degree of stability in the divine regard. An attempt has been made to prove these ordinances to have been designed to endure to all eternity, from the very nature of the laws by which provision is made against any derangement of the heavenly mechanism—laws strongly indicating an intention on the part of the Creator that they should continue in operation for ever; and we appear to have in the above quoted passage a strong corroboration of this view, seeing God appeals to those ordinances as a standard of never ending duration.

'he difficulty in the way of this conclusion, arising out of the apparent irregularities of the cometary system, has already been considered. But there remain certain other phenomena to which the doubtful may appeal, and to which due weight must be given. The objector may say—"Have we not heard of stars, long familiar to the astronomer, which are now sought for in vain? of others which have made their appearance, and waxed brilliant in splendour, but which, after astonishing the star-gazer for a season, have gradually faded from his view? And how do these facts consist with

the alleged permanence of the present material arrangements of the world? Do not these phenomena indicate the formation of new orbs, and the annihilation of old?"

Now, doubtless, instances both of the disappearance of known stars and of the arrival of new ones have occurred. Of the earlier instances of the latter phenomenon too little is known to make them worthy of remark. The first new star of which we have any distinct account is one which appeared in 1572, which was observed with great care by Tycho Brahé. When first seen by him it rivalled in splendour the planets Jupiter and Venus, and continued to shine with undiminished lustre for about a month, after which it began to fade, and in about five months it ceased to be visible. During its stay it underwent various remarkable changes in its appearance. When first seen its light was bright and white, like that of Venus. It afterwards became yellowish, then ruddy like Mars, and finally of a dull palid hue like Saturn. Another similar object was discovered by Kepler in 1604. It also was at first brighter than Jupiter, but after blazing for awhile, it began gradually to fade, and was lost to view about eighteen months after its first appearance.

Similar phenomena have since been observed, but none on so remarkable a scale. Other stars known to astronomers are also believed to have undergone an apparently permanent change in their brightness.

Now, these are certainly startling facts, but are they not capable of explanation without resorting to the violent supposition of new stars having been created, of old stars having been annihilated, or of others having undergone a permanent change in their physical constitution? It has been shown that many of the central luminaries have remarkable proper motions of vast extent. Now, the paths in which these

motions are performed may be variously disposed with respect to the earth. Some of them may be so situated that the star, in describing its vast orbit, may recede to a great distance from our globe, and so dwindle very considerably in magnitude. The orbits of some of them may resemble those of the comets, and be very elongated ellipses. Those stars which appear for a season and then depart may be visible to us only while traversing that portion of their path which is nearest to our system.

It is not, indeed, to be denied that some bodies in the universe may be undergoing violent chemical changes within themselves, which may be evidenced to us by their suddenly becoming luminous, but such changes have proceeded, and may yet occur, without derangement of the general mechanism. This globe of ours might be wrapt in one vast conflagration, and yet pursue its journey round the sun in its wonted path without the slightest disturbance. It is quite possible, therefore, that the stars of 1572 and 1604 may have been bodies in a state of violent combustion. It appears probable, however, that even were such one principal cause of the phenomenon, a large portion of the effect must also be attributed to changes of position and of distance, caused by the proper motion of the orb.

It is remarkable, as bearing upon this question, that no star has ever made its appearance suddenly, or even by slow degrees, and remained permanently in view. All new stars have gradually vanished within a short time after their first appearance, thus rendering it obvious that no permanent addition has been made to the heavenly orbs within the historic period. As little can it be affirmed that there has been any such thing as the annihilation of any already existing star. Those which have disappeared have faded by slow degrees showing that increase of distance, and probably

the difficulty of recognising them among so many millions of stars of small magnitude, is the true cause of their apparent loss. The phenomena of new and lost stars, therefore, do not warrant any inference hostile to the idea that the grand system of the material universe has been designed by its Author to endure for ever.

CHAPTER XII.

"The works of the Lord are great, sought out of all them that have pleasure therein he hath made his wonderful works to be remembered."—Ps. cxi. 2, 4.

It is now time to call to remembrance the various points of interest in relation to the Host of Heaven which have been brought under review, so that we may meditate upon them, regarding them in the special light of their being the works of God the Eternal. It has been shown that the universe is composed of an unknown but very great number of stellar systems, placed at immeasurable distances from one another, and that our sun with his attendant planets forms only a very inconsiderable portion of one of these numerous groups. That the stellar system to which we belong embraces not only all the stars discernible by the naked eye, but also the whole of that enormous compact mass of stars known as the Milky Way; every star, in short, which is readily distinguishable as a separate body either by the naked eye or by ordinary telescopic aid. That the other stellar systems are so distant from us that, when viewed even by telescopes of high magnifying power, they appear only as a luminous haze, and that it is not till instruments of the highest excellence are brought to bear upon them that they are discerned to be composed of separate stars like our Milky Way.

It has been further mentioned that not only do the planets, with their attendant satellites, move round the sun, but that our great luminary himself, with all the planets, in like manner performs a revolution round a very distant point near the centre of the system to which he belongs, and that every star in the system is affected by a similar motion of revolution round that same centre.

Now, wherever a motion of revolution exists, there also exists the tangential force, and were it not counteracted, the whole revolving bodies would be continually flying further and further from the centre of motion; but this is prevented by the countervailing force of gravity. Hence the existence of a motion of revolution becomes itself an evidence of the operation of the force of gravity; so that the motion of the sun and the fixed stars round a centre proves that the whole of the stellar system, to which we belong, is under the force of gravitation, by which, and by the countervailing tangential force its component bodies are retained at their proper normal distances from each other.

With respect to the other stellar systems which appear to us as nebulæ, it cannot be so directly proved that they are pervaded by the force of gravity, because we cannot discern the motions which may exist among their component orbs. But the analogy of nature leads to the inference that in these also this all-pervading force must exercise its sway. The very circumstance of the stars composing these nebulæ being held together at distances, so small in comparison with those which separate one nebula from another, is a proof that they must be retained at those small mutual distances by some pervading force. Again, although we cannot perceive the component stars of the nebulæ to be actually in motion, yet the different forms, under which the nebulæ present themselves, have been shown to be precisely such as would be assumed, on the supposition that the component stars do revolve round a common centre under the influence of the tangential and gravitating forces, and that probably each nebula, in virtue of the operation of those forces, passes in succession through all the three forms, the globose, the annular, and the spiral. There is thus a strong body of evidence tending to prove the stars composing the nebulæ to be under the government of

the same forces which regulate those composing the stellar system, to which our sun and his planets belong.

It is necessary however to go a step further. If the force of gravity subsist in every separate stellar system, then must all these gravitate towards each other, so that, in the absence of any countervailing force, there would be a perpetual tendency to indefinite mutual approach, resulting in the ultimate total derangement of the universe. But as within the whole range of our experience we observe that, wherever the force of gravity exists, its tendency to cause all bodies to lapse into one is uniformly countervailed by the tangential force attending upon revolution round a centre; it becomes highly probable that this compensation extends, on the great scale, to all bodies in the universe, and that their gravitation is exactly counterbalanced by some motion of revolution performed by each stellar system in some vast orbit in countless ages of time.

It thus appears that the force of gravity pervades every portion of the universe, and the entire mass of every ponderable body composing it. Now, no force can exist abstractly as such. Force is a quality, not a being; and we cannot conceive of it except as exerted by a *somewhat* occupying the point of space whence the force emanates. It is thus needful to regard every gravitating body as an aggregate of those somewhats in which the force of gravity resides, and these have accordingly been designated "the ultimate ponderable molecules of bodies." Some philosophers, indeed, have dreamt of dispensing with these fountains of force, contending that as we can prove only the existence of the force, we are not entitled to assume that anything more exists. But this view overleaps the intuitive perceptions of the human mind, which regards force as the very best evidence of the existence of substance or being; and it cannot, if it

would, divorce the one idea from the other. Some allege it to be as impossible to conceive of substance exerting force beyond the limits of its own immediate presence, as it is to imagine force to exist abstractly. But this is not the case. There is nothing absurd in the notion that substance, if it exert force at all, may exert it at any distance whatever; because force involves of necessity the idea of an influence exerted by one somewhat upon another somewhat out of and beyond itself. Distance thus enters as an element into the very conception of force; for were there even two points in space exerting force one upon the other, there must be distance between them, however small. But the magnitude of the distance is no element in the idea. It may be anything whatever; consequently it is not difficult to conceive of substantial molecules exerting force at a distance from the sphere of their immediate presence; whereas it is impossible to imagine nothing, or mere space, to exert any force whatever.

Viewing the heavenly orbs, then, as composed of atoms, each endowed with the force of gravity, exerted at any distance from itself, however immense, it is plain that these atoms must be each a distinct, independent essence or being, separated from every other by a space or spaces, however small. It is demonstrable that the larger portion of the bulk of even the heaviest and densest bodies is made up of such spaces or pores, separating their component molecules from each other, and allowing of their mutual approach, or divergence, and of their performing minute gyrations of greater or less amplitude, to which are due all the phenomena of temperature.

CHAPTER XIII.

"I meditate on all thy works; I muse on the works of thy hand."—Ps. cxliii. 5.

Withdrawing our thoughts for a brief space from the contemplation of the universe in its vastness, let us concentrate our attention on one of those minute molecules, of which it has been shown all heavy bodies must be composed, and which are the seats or centres of the force of gravity. Let us consider how varied and complex are the motions by which such a molecule is continuously and simultaneously affected, although to our senses it appears absolutely still. Take, for example, any individual atom entering into the composition of a stone, upon the surface of the earth. It is constantly performing, within the stone itself, a minute motion incident to its temperature. It participates with the stone in its daily motion round the axis of our globe, and in the more gradual movements involved in the oscillations of that axis. It partakes with our planet in its annual motion round the sun, and in all those slower movements, whether of rotation or oscillation, by which the planetary system is upheld. It follows the sun in his vast orbit round the centre of the stellar system, to which he belongs; and lastly it accompanies that stellar system itself in sweeping through space, with that yet larger motion which appears needful to prevent the nebulæ from indefinite mutual approach.

If to these complex motions, by which every molecule of our globe is simultaneously affected, we add those others with which some are endowed, the mind becomes bewildered in the contemplation. Reflect, for example, on the motions of a molecule of water on the surface of the sea, or of a mole-

cule of air in a whirling breeze, and consider the varied movements which each of these performs in addition to those above enumerated. Or take the yet more striking example of a molecule entering into the composition of the balance of a watch, which not only performs its own peculiar oscillatory motion in the machine, but is further affected by every movement of the wearer—by the beating of his heart, by the heaving of his chest, by his every alteration of position, by his every change of place; while, simultaneously with these peculiar movements, it is all the while participating in those others which affect all the molecules of our globe.

Thus it will be seen that perpetual motion is an all pervading law of the universe, and that no ponderable molecule in it maintains the same position in absolute space for two consecutive instants of time; so that of each it may be every moment affirmed, as regards absolute space, that "the place which knoweth it now, shall know it no more for ever."

While it has thus been made evident that, wherever the force of gravity exists, there also motion is found as a necessary accompaniment, such motion is not to be regarded as *caused* by the force of gravity itself; for were it so generated, it would result in the final collapse of all bodies into one. The force of gravity merely influences the direction and species of the motion; but it cannot be the generating power, seeing the motion tends for the most part to counteract, rather than implicitly to obey the force of gravity. Now, in the same manner that the human mind cannot conceive of the force of gravity, as existing by itself alone, or as being exerted by nothing, so it cannot regard motion as existing without some moving power; and as that moving power cannot be either the force of gravity itself, or that which exerts the force of gravity, it must be something which lies beyond and out of the material masses that are moved. The mind

thus arrives at the conclusion, that there must be in the universe a *prime mover*, a Being capable of exerting force or power.

But further, when we contemplate the nature of the motions performed, and the laws by which they are regulated, we cannot fail to perceive that, besides power, there is a manifestation of will, design, purpose, plan, intention. Again, in the same manner as the mind is unable to conceive of force residing in nothing, it is unable to imagine will, design and intention as existing in, or being exerted by nothing, or by those things which are themselves the passive subjects of the design. The mind is thus led to perceive that every design must have a designer, every intention an intending will. Hence the existence of the movements of ponderable bodies, and in an especial manner of the wonderful motions of the planetary masses—exhibiting, as they do, such marvellously skilful design, and such an evident intention to preserve them in perpetual operation,—constitutes an incontrovertible proof that there exists in the universe a great Moving Power, and that that power can be no other than a willing, designing, intelligent and forecasting Mind.

CHAPTER XIII.

"Behold, the heaven, and heaven of heavens, cannot contain thee."—
1 KINGS viii. 27.

THE ancient Hebrews appear to have recognised three heavenly regions—the aerial heavens, the starry heavens, and the heaven of heavens. This last seems, according to the popular belief, to have been regarded as the special abode of the Deity and of the angels. Here they imagined the Supreme to be perpetually seated on a superb throne, enveloped in a blaze of luminous splendour, and surrounded by an innumerable host of angels, continually hymning his praise, ministering to his pleasure, and executing his commands.

This idea may be traced to the visions of the prophets. The popular mind, forgetting that these visions were for the most part mere emblems of moral and spiritual truths, gave them a literal interpretation. They regarded them as glimpses, vouchsafed to the seers, of an unseen spiritual world, having an actual existence in some unknown region of the universe. These popular notions have descended to modern times. The above sketch of the heaven of heavens accordingly represents the conception entertained, at the present day, by a large proportion of mankind, and even by many intelligent minds.

This idea, however, is based on very erroneous views of the mutual relations between mind and matter, and of the general structure of the physical universe. But that some of the ancient Hebrews entertained far higher and more accurate ideas, is evidenced by the passage above quoted,

and also by the 139th psalm, in both of which the important doctrine of the divine omnipresence is clearly taught.

Although frequent mention be made in Scripture of created beings superior in intelligence to man, and dwelling in some region of the universe beyond the earth, yet there cannot be traced any very distinct intimation of the site or nature of their abode. It is, however, indicated that these superior beings are endowed with a faculty enabling them to leave their own habitation, to visit this earth for a brief season, and then to return whence they came. At least such an inference may be reasonably deduced from the statements of Scripture. They are in Hebrew called מלאכים *Malachim*, messengers, the word being several times used in Scripture in this lower sense. This circumstance shows that the idea of locality, or position in space, entered, as a necessary element, into the Scriptural conception of an angel. For it is impossible to imagine a being passing from place to place, unless it be of such a nature as to have a limited position in space.

Some metaphysicians, indeed, have maintained that locality cannot be correctly affirmed of pure spirit or mind; but this is a mere sophism. For reason intuitively perceives, that whatever exists at all must exist either everywhere or somewhere, and that what is nowhere can have no actual existence. It is in that case a mere mental abstraction. To affirm, then, that a pure spirit or mind has no locality is to reduce it to an abstract idea; so that, according to this view, angels would be mere creatures of the imagination, like fairies or sylphs, and have no real existence in any place whatever.

When the intelligent mind reflects on the constitution of the physical universe, as unfolded by the discoveries of modern astronomy, it ere long arrives at a conviction, that

the popular notions respecting heaven and the angels must be banished into dreamland. These discoveries show that the physical universe consists of an illimitable elastic ether, whose waves awaken the perception of light, and of countless millions of ponderable orbs floating in this boundless ethereal expanse. Assuming then the existence of angels as a reality, and not as a mere figment of the fancy, there are only two regions which can be regarded as their abode—either the orbs floating in the ether, or that elastic medium itself. There is no third region which can be assigned for their dwelling-place.

A little consideration will suffice to indicate that the ether itself cannot be the abode of the angels. For every angel must have a limited presence—God alone being omnipresent; and as mind does not limit mind in space, and does not in itself possess any form, the limits by which the presence of any created mind is bounded must be material. Now, for a being to have a limited presence in any medium, the matter constituting the sphere of its presence must differ in kind from that of the medium. No being could have a limited presence in water were it composed entirely of water, or in air were it composed of air, or in ether did it consist of mere ether. Hence the matter, by association with which the mind of an angel must have its presence limited and localized, must differ in kind from the ether. It must have a definite form. It must, in short, be an organic structure, fitted to subserve the purposes of mental activity, and composed of ponderable substance, so as to bring the mind into active relation with that species of matter. But a ponderable organism could not exist, save in a habitation also composed of ponderable substance. Hence, of the two abodes to which we are limited, the orbs floating in the ether, and not that medium itself, must be the habitations of the angels.

We are thus led to the conclusion, that the created beings of an intelligent order, which are mentioned in Scripture under the appellation of angels, are just the inhabitants of the other globes, distributed in such vast profusion throughout the universe; and we may imagine the organic structures, by which their presence is limited within their own habitations, to be in every respect suited to the physical peculiarities of the orbs in which they dwell.

CHAPTER XIV.

"Bless the Eternal, ye his angels! mighty in strength, doing his word, hearkening to the voice of his word."—Ps. ciii. 20.

REASONS having been assigned for holding the angels, mentioned in the above and other passages of Scripture, to be the intelligent inhabitants of the various orbs of heaven, the only remaining difficulty is to form a definite conception of the manner, in which these beings may execute their missions. But here also science comes to our aid. It has been shown that all ponderable bodies are continually moving through the universal ether with immense speed, consequently every human mind and every angelic mind is constantly traversing the ether in company with its material organism. Now, the relation of mind to matter subsists between the being endowed with life, and the ultimate molecules of material substance. The individual atoms, thus brought into connection with the living being, are perpetually changing. Fresh molecules are continually brought into this relation, while the old ones are cast off. Thus, also, the number of atoms, under the control of any living being, is always varying.

In the case of man, these changes are accomplished according to certain organic laws; nevertheless, volition enters largely as an element into their operation. Now, it is not pushing the method of reasoning by analogy too far, to suppose that, in the case of angels, the element of volition may enter more largely into the process, and that these beings may be endowed with a faculty of altering at pleasure the material molecules, both as regards individuality and number, with which their minds are in immediate relation. Going a

step further, we may imagine that, when it becomes needful for any special purpose, they have the power of withdrawing their spirits completely from all connection with the ponderable atoms, and confining their relation to the individual ultimates of the ether. Or, we may suppose this operation to be effected by some special divine action, exerted on these angelic beings.

As each individual ultimate of the ether has a fixed position in space, were a living spirit to become associated solely with such an ultimate, it would have a similar fixedness of position. It thus becomes further necessary to imagine, that the Deity causes the living spirit on its becoming thus limited, to pass from ultimate to ultimate of the ether, much in the same manner as it passes from ultimate to ultimate of ponderable substance, or as it traverses the ether in company with the ponderable molecules of its organism, only with far greater speed.

This conception enables the human mind to form a distinct idea of the manner in which a created spirit may pass from orb to orb of the universe. Suppose an intelligent inhabitant of any of the other planets, say of the morning star, to be commissioned by the Deity to convey a message to an inhabitant of the earth. The angelic spirit will first become disengaged from all connection with the ponderable atoms of its organism, in virtue either of a voluntary effort, or of a special divine influence. The presence of the living being will thus become limited to an association with one or more ultimates of the elastic ether. His native planet, as it will meanwhile be traversing the ethereal expanse with great velocity, will leave behind it the angelic spirit in a fixed position in the great ocean of ether, and freed from all connection with any ponderable substance whatever. We may then suppose the spirit to be, by a special divine influence

exerted on it, transported from ultimate to ultimate of the ether, in a manner resembling that in which the impulse travels in the case of a wave of light, and with similar speed. He will thus in a few minutes reach the earth. Here he may again, by a special divine influence, be endowed with power to act on ponderable substance, and to assemble around him a sufficiency of atoms to constitute a temporary organism, to all outward appearance resembling the human, perhaps even identical with it in its intimate structure. He will thus be brought into a condition the fittest for enabling him to discharge his commission. His message delivered, he may again dissolve his connection with ponderable matter, dissipating his temporary organism, and restricting himself to the ultimates of the ether. He will thus be enabled to return to his own abode, there to resume the organism fitted to the physical peculiarities of the planet in which he dwells; while that organism may in the interval have presented the appearance of a body in a state of suspended animation.

There is in this hypothesis nothing from which human reason need recoil. It is a fair case of analogical argument, and lies quite as much within the bounds of probability, as many others with which the human intellect is content to rest satisfied, when certain knowledge is unattainable. There is thus nothing *irrational* in the idea, that the inhabitants of other worlds may be occasionally commissioned to visit this earth on errands of love and mercy, in cases where some great moral end is to be attained by such a method of accomplishing the divine purposes.

The foregoing, however, is only one of the possible modes of explaining the Scriptural narratives respecting angelic visits. There remains another equally reasonable. God has so constituted the human mind that, in its estimation, the apparent is practically equivalent to the real. Hence the

Scriptural accounts of the appearance of angels might be explained by supposing the Deity to have, on those occasions, exerted upon the human sensorium a peculiar action, in virtue of which the individual so affected saw a beautiful human form, and heard certain words which that form seemed to pronounce; yet all the while there may not have been really present any created being, whose image he saw and whose voice he heard. The phenomena might have been purely mental. The image and the voice may have existed only as illusory impressions on his sensorium, which the individual was unable to distinguish from realities. Were this latter explanation accepted, however, it would be legitimate to infer, that the Deity preferred, to others which might have been adopted, this peculiar method of making important communications to men, for the express purpose of intimating to the human mind the existence of other intelligent creatures, who inhabit the various habitable worlds, scattered in boundless profusion throughout the infinite ether.

The ridicule which some sceptics have cast upon the Hebrew and Greek Scriptures, from the circumstance of their making mention of angelic visits, has, accordingly, no just foundation in reason; for these narratives admit of explanation on rational principles. The ridicule is justly attachable only to the popular notions respecting angels—to the conception of their being furnished with wings, and flying through the air like birds or bats, or to the idea of their inhabiting some unseen region termed a spiritual world, lying immediately outside of the limits of this globe, or perhaps in the exterior portions of its atmosphere. Such notions are indeed ludicrous, because they are inconsistent with our present knowledge of the physical structure of the universe. These ideas, however, are based, not on Scripture itself, but on misconceptions of Scripture. They have ori-

ginated in the supposition, that the dreams and visions of the ancient prophets were exhibitions of realities, instead of being, as they actually were, representations by symbol of great spiritual and moral truths, produced by special divine influence on the imagination of the seers.

While physical science thus dissipates the illusion still lingering in the popular mind, that heaven is a vast region in some unknown quarter of the universe, where the Deity is continually seated on an exalted throne, surrounded by angels, wearing forms resembling the human, but with the monstrous addition of wings attached to their shoulders, it enables us to entertain a far more enlarged and glorious conception. It allows us to believe that, instead of one, there are millions of heavens, inhabited by intelligent beings, all capable of rendering a rational and willing obedience to their Creator, of admiring his works, revering his wisdom, and adoring his goodness. We are left free to imagine that into many of the numerous globes inhabited by those beings, moral evil has never found its way, and that, consequently, their inhabitants are as pure and holy as they are intelligent. We may believe that in all such worlds the Deity manifests his immediate presence, and holds direct intercourse with his intelligent creatures. Finally, we may indulge the delightful hope that this earth will, at some future period, become itself a moral heaven, in which the righteous shall dwell for ever, and that our globe will, like the other heavenly orbs, of which it is one, be then blessed by a special manifestation of the divine presence, in virtue of which God will maintain with man such an immediate intercourse as he now holds with the angels. In this manner may be fulfilled the prophecy, that, "the meek shall then inherit the earth, and delight themselves in the abundance of peace."

PART II.

The Universal Ether.

Th' Ether, subtle and immense,
  To describe we venture;
Nowhere its circumference,
  Everywhere its centre.
Of the Ether, by our sight.
  We acquire our notions;
For the shining rays of light
  Are its wavy motions.

PART II.

The Universal Ether.

CHAPTER I.

"Where is the way where light dwelleth?"—JOB xxxviii. 19.

IN putting this question to the patriarch, the Divine Speaker challenges the human mind—propounding this inquiry as lying beyond the reach of its limited powers. By "the way where light dwelleth," is to be understood the primary source of light, and the manner of its origin—not the nature of light, and the mode of its action. The latter lie within the boundaries of legitimate research; for by an attentive study of the phenomena, and a careful application of the inductive method of philosophy, the human mind may arrive at a certain amount of knowledge, respecting the nature of light; although it may never be able to penetrate the secret of its primary origin. The Lord's challenge to the patriarch is not, therefore, to be understood as a dissuasive from all inquiry into the nature and laws of light, as being futile and fruitless, but merely as indicating the limit, beyond which our researches cannot extend.

In giving a brief outline of our knowledge respecting the hosts of heaven, and the laws by which they are governed, it was pointed out, that the universe embraces matter in two very different modes of existence in space—the one accum-

ulated into distinct separate masses, under the influence of the force of universal mutual gravitation; the other universally diffused, in the form of a subtle elastic ether. It is to the phenomena of light, that we are chiefly indebted for our knowledge of matter in this latter mode of existence; and as our ideas respecting the material universe, its laws and its endless durability, must be greatly influenced by our notions, in regard to this subtle ethereal medium, our sketch would be incomplete without some notice of those phenomena, on which our ideas must be based. This is all the more needful; because, even at the present time, much misconception on this point prevails.

It is generally known, that the opinions of philosophers have long been divided on the subject of the nature of light. One set, following Sir Isaac Newton, regard all luminous phenomena as due to minute particles emitted by the luminary —an opinion designated the theory of emission. Another set, adopting the ideas of Huygens and Dr. Young, regard these phenomena as due solely to the undulations of an elastic ether; whence this opinion is called the undulatory or wave theory. It must not be supposed, however, that the question of the existence of an universally diffused elastic ether depends entirely on the view, which philosophers now entertain upon the question, whether the phenomena of light be produced by emitted particles, or by mere undulations; for, as will hereafter appear, the assumption of the existence of an elastic ether is quite as indispensable to the theory of emission as to that of undulation.

It would be out of place here to give a description of all the varied and beautiful phenomena of light and colours, or to enter into subtle disquisitions in regard to their bearing on the two theories. Attention shall be confined to a very few of these phenomena, and only to such as furnish materials

for forming a judgment on the respective merits of the theories, in accordance with the present state of our knowledge.

The speed with which light travels is a phenomenon alike remarkable in itself, and important in its theoretical bearing. The first method of determining it is by observing the difference between the times of the eclipses of Jupiter's satellites, when that planet is nearest, and when he is furthest from the earth. These observations show that light takes 16′ 26″ to traverse the diameter of the earth's orbit, a distance estimated at 190,000,000 of miles; whence the rate of speed appears to be 192,700 miles in a second.

A second method of ascertaining the speed of light is from the aberration of the fixed stars, that is, their difference of position, when viewed from opposite sides of the earth's orbit, and when the earth is moving in opposite directions. The constant of this aberration is now ascertained to be 20′ 36″. The reciprocal of the sine of that angle, multiplied by the rate of speed at which the earth travels in its orbit, determines the swiftness of light to be 192,000 miles in a second.

The third method of determination is by direct experiment, made on light traversing a given distance near the earth's surface.

By an ingenious apparatus, M. Fizeau succeeded in ascertaining the speed of light, in going through a space of 9440 yards, to be about 196,000 miles per second, an estimate considerably exceeding the other two. This discrepancy, however, may now be reduced, by its having been ascertained from recent observations, made by American astronomers, that the sun's mean distance is 96,160,000 miles, instead of 95,000,000 as hitherto estimated. This raises the rate, as determined by the first method, to 195,000; and by the second method, to 194,000 miles per second—results ap-

proaching considerably nearer to that obtained by M. Fizeau, and presenting an agreement, as near as can be expected in such an inquiry. For in the experiment of M. Fizeau, the result represents the speed with which light travels through air, of the density which it has at the earth's surface; but in the case of the light coming from Jupiter's satellites and the fixed stars, it may have had to pass not only through the whole of the earth's atmosphere, but perhaps also through other media, as, for example, through atmospheres surrounding these satellites or the fixed stars, which may affect the speed of the light; for that the speed of light must be affected by the medium through which it passes, is a conclusion deducible from either of the two theories. There is, however, this remarkable difference between them, that, according to the theory of emission, light should pass more rapidly through dense, than through rare media; whereas from the theory of undulation the conclusion is the reverse.

It was accordingly an important point, to determine accurately what is the state of the fact, as regards the effects, produced by different transparent media, on the speed of the light passing through them. The general result, that the light apears to be slightly retarded in coming from the fixed stars and Jupiter's satellites, seems to indicate its being exposed to some retarding influence, by its having to pass through other media besides the free ether and the earth's atmosphere; but the difference is too slight, and the chances of error too great, for absolute reliance. M. Fizeau has, however, by another ingenious experiment, determined this point also. By the combined action of a fixed mirror, with another revolving very rapidly, a difference in the rate at which light travels, through different media, in traversing the short distance of twelve feet, was rendered so sensible,

as to admit of accurate measurement. On comparing, by this method, the speed of light in air and in water, M. Fizeau found, that the rate in air exceeds that in water, in the proportion of nearly 133 to 100. Now this is precisely the result, which ought to arise according to the theory of undulation; whereas, according to the theory of emission, the result ought to have been the reverse; the light ought to have travelled slower through air than through water, in the same proportion of 133 to 100. The question is thus removed from the region of theory to that of fact, resolving itself into the trustworthiness of M. Fizeau's experiments; and, fortunately for the interests of science, these were corroborated in a remarkable way. For it so happened that another French philosopher, M. Foucault, had, unknown to M. Fizeau, performed the same experiments with a like result a short time previously; and the communications of both philosophers were submitted to the French Academy on the same day. The results thus obtained by Messieurs Foucault and Fizeau, moreover, tally with those previously obtained by M. Arago from a totally different method of experimenting, by which a variation in the speed of light was made apparent to the eye in traversing an equally short space. But on that experiment implicit reliance could not be placed, so long as it stood alone; it having been based on certain principles peculiar to the theory of undulation.

The two experiments taken together, however, present a strong evidence that the speed of light, in traversing water, is less and not greater than in traversing air.

The decision between the two theories might be allowed to rest on this single phenomenon alone; but there are a few others, which it may be well to notice, as tending to establish the same conclusion.

CHAPTER II.

"By what way is the light parted?"—JOB xxxviii. 24.

WHEN light falls upon any surface, it becomes separated into two distinct portions; the one entering the substance, the other being turned backward from the surface. Each of these portions becomes further subdivided. That which enters the body separates again into two parts, one of which, in certain cases, passes through the substance, emerging at the other side, the other becoming absorbed, as it is called, or seeming to disappear altogether. The portion which is turned backward from the surface is likewise divided again into two parts, of which one is *regularly* reflected, the other scattered in all directions.

Of the portion which enters the body, the part transmitted and the part absorbed bear diverse proportions to each other in different media. Some media are almost perfectly transparent, and in these the proportion of light transmitted very greatly exceeds that which is absorbed; yet no substance is so absolutely transparent, as to allow the whole of the light which enters it to pass through it, without any absorption. On the other hand, many substances absorb nearly the whole of the light which enters them; but even the most opaque substances allow a small portion of light to pass through them. Gold leaf, for example, allows a considerable amount of light to pass through it, imparting to it a greenish tint. Even charcoal, when reduced to thin films, as may be done by charring elder pith between plates of glass, transmits an appreciable amount of light, merely giving it a brownish hue. Opacity and transparency are accordingly mere relative terms.

The portion, which is absorbed, is only apparently lost. It is really employed in communicating vibratory motions to the ponderable molecules of the substance into which the light enters. One part of this motion is made manifest by a rise of temperature; and this is particularly the case with bodies that are either quite black or of a very dark colour. But in all coloured bodies, particularly those exhibiting bright tints, the motion imparted to the particles of the substance by the entering light, is manifested by the property which they acquire, of as it were forming a new light of their own, having their distinctive colour. They temporarily become luminaries under the influence of the light which they receive from without; and it is chiefly by this new light of their own generating, that such substances are visible. The colours thus produced sometimes affect the light passing through the substance, sometimes that which is scattered in all directions from its surface, but never that which is thence *regularly* reflected, and which is always of the colour of the incident light.

When a substance imparts colour both to the transmitted light, and to that scattered from its surface, it occasionally happens that these two portions differ in colour. In some few instances also rays of light, which are incapable of exciting vision, when received by the eye directly from the luminary, become visible and coloured, by first falling on the surface of a medium, and exciting it to generate rays, which are capable of producing the impression both of light and colour. Of this phenomenon, which is termed fluorescence, fluorspar and the solutions of quinine, and of the bark of the horse-chestnut furnish remarkable examples. In such cases, however, we have no warrant for supposing the identical rays, primarily invisible, to acquire visibility and colour, from the action of the medium. The more reasonable

conclusion is, that these invisible rays excite, in the particles of the substance, motions, which, in their turn, generate *new* light, possessing both visibility and colour. This view is strengthened by the circumstance, that the weak light of a spirit-lamp, and the yet feebler light of the aurora borealis act powerfully in exciting the luminosity of fluorescent substances.

The foregoing view of the colour of natural bodies was first propounded, it is believed, by Baron Wredé, and is supported by numerous striking facts. It is not to be denied, however, that colours are sometimes produced by other causes; such, for example, are the colours exhibited by thin films of mica, by soap-bubbles, feathers, or the like; but these colours are accidental, and changeful in their appearance. They are caused by the impression, produced on the eye, by the light coming from one surface, being interfered with by the impression produced by the light coming from a second surface, at a very short distance behind the first. Such colours are known as those of thin plates, but they differ essentially from the natural colours of bodies; and although it was at one time imagined, that these last were due to a similar cause, that idea is now found to be untenable, and Wredé's view, that the natural colours of bodies are due to a proper light of their own, which they generate under the stimulus of the light falling upon them, rendering them temporally self-luminous, appears entitled to the preference. This view, however, accords only with the theory of undulation; and it follows from it, that the light, which is not regularly reflected from the surfaces of bodies, but scattered in all directions, whether white or coloured, is really not a portion of the incident light thrown backwards, but a specific light, generated by the substance. under the stimulus of a part of that portion of the incident

light, which seems to be absorbed; the remainder of that portion going either to affect the colour of the transmitted light, or else to produce a rise of temperature.

That portion of the incident light which is regularly reflected obeys a uniform law. The inclination of the reflected light to the reflecting surface, is always the same as that of the incident light, but in an opposite direction. This law is deducible equally well from the two theories. The quantity of light, thus regularly reflected, depends on two circumstances. 1*st*, It is directly proportional to the degree in which the incident light is inclined to the surface. The further from the perpendicular, the greater the amount of reflected light; and a degree of inclination may always be found at which the reflection is total. 2*dly*, The quantity of regularly reflected light is in direct proportion to the smoothness and perfect polish of the surface. But in smooth surfaces the quantity varies with the inclination in different bodies. Thus, at moderate inclinations, glass reflects more light than water; but, where the inclination is great, water is the better reflector of the two. The light which is regularly reflected from a perfectly smooth and polished surface, is never affected in colour by the substance of which the surface is composed, but is always of the same colour with the incident light, thus proving it to be truly a portion of that light. The light which is thus regularly reflected is inversely proportional in quantity, to that which comes to the eye, altered in colour by the substance of the surface; the former being greater, the latter less, the more obliquely the surface is viewed.

With respect to that portion of the light, which enters the medium, on which it falls, penetrating through the first surface, and emerging at the second, it is affected in its direction by two circumstances—the nature of the medium,

and the degree of obliquity with which the light enters it. When it falls perpendicularly, it passes through the medium, whatever it may be, without any alteration in its direction; but when it falls in any degree obliquely, it has its direction altered, and that to an extent proportionate to the degree of obliquity. If, at any given distance from the medium (say an inch), a line be drawn parallel to its surface, so as to join the oblique ray with the perpendicular, and if, at the same distance *within* the medium, a similar line be supposed to be drawn parallel to the first, the proportion, which the outer line bears to the inner, is termed the index of refraction. When the light passes from a rarer to a denser medium, the outer line is the longer of the two; but when it passes from a denser to a rarer, it is the reverse. Hence the inner line is the shorter, whenever the light passes from free space, or from the free ether, into any medium; and the index of refraction is the number of times which the length of the outer line exceeds that of the inner. The outer of these two lines is called the sine of the angle of incidence; the inner, the sine of the angle of refraction; and whatever be the size of the first of these two angles, the proportion, which its sine bears to that of the second, is constant for the medium and temperature.

This law is deducible equally well from the two theories, but in different ways. In the wave theory, it is the mathematical result of the laws of undulation; but, in the theory of emission, it is supposed to be due to an attractive force, exerted on the luminous particles, by the surface of the medium. According to the wave theory, the change of direction is attended by a retardation of the wave-motion. According to the theory of emission, it is attended by an increase of speed, communicated to the luminous particles, by the attractive force of the medium.

But at this point, the theory of emission is met by a great difficulty. Why do some of the luminous particles obey the attractive force, and pass into the medium, while others are repelled from it and reflected? This separation of the light, into a reflected and transmitted portion, is the mathematical result of the theory of waves; but its explanation, according to the theory of emission, can be effected only by a very forced supposition—namely, that the luminous particles are alternately predisposed to yield to the attractive and repulsive forces. These alternations were termed, by Sir Isaac Newton, fits of easy reflection and easy refraction. But this explanation goes only half way; for it leaves in the dark both the nature of these fits and their cause. On this point there appear to be two possible suppositions. The luminous particles might be endowed with poles, similar to those of a magnet, and might be in constant rotation during their progress, so as to present these poles alternately to any opposing surface, which would attract or repel them according to the nature of the pole. Or, secondly, the luminous particles might be preceded in their course by the waves of an elastic ether, by which their progress might be alternately quickened or retarded; and they might be disposed to yield to the attractive or repulsive force, exerted by the surface, according as they might happen, at the moment of meeting it, to be in a fit of retardation or acceleration. The latter is the idea to which, it is believed, Newton himself had a leaning; and as it comes into requisition in order to explain another phenomenon, it seems entitled to the preference.

But the question, between the two theories, comes to an issue in that of the rate of speed which the light acquires in passing through the medium. If it could be shown that the rate of speed is quickened in the denser medium, then the theory of emission would be preferable, because this accele-

ration is the necessary result of its explanation of refraction. But if the speed be slackened in the denser medium, the preference must be given to the wave-theory, because such retardation is the necessary consequence of its mode of explaining refraction. Now, as it has been shown experimentally, that the speed is *retarded* in the denser medium, the preference, as regards the explanation of refraction, is due to the theory of waves.

CHAPTER III.

"I form the light, and create darkness."—ISA. xlv. 7.

THE last of the affections of light, which was noticed, was that of its being turned out of its course, in passing from a rarer to a denser medium, or the reverse—it being turned *towards* the perpendicular in the former case, and *from* it in the latter—a change of direction which is termed refraction. The phenomenon is exhibited in this its simplest form by all transparent substances whatever. But there are some transparent media, in which it is found that the transmitted light is divided into *two* separate beams, which follow distinct paths—a phenomenon termed double refraction. This is readily explained in accordance with the wave theory, by supposing the medium to exert upon the ether a compressing force, which is different in different directions; so that the wave motion travels at different rates of speed in these two directions—thus giving rise to two distinct sets of waves. But, in accordance with the emission theory, the medium is supposed to have certain axes of attractive force, arising from its density being different in one direction from what it is in another,—one portion of the luminous particles yielding to the influence of one set, and another portion to that of another set of these forces. This explanation, however, appears to involve the idea of the luminous particles being endowed with poles.

This last notion is apparently favoured by the circumstance, that, when light is thus divided into two separate beams, on passing through a medium, these two beams are found to differ in certain particulars, and to possess unlike

sides. They cease to be capable of reflection on one side, and of refraction on the other, and this oppositely—the side that is incapable of reflection in the one beam, being that which is incapable of refraction in the other. The light is then said to be *polarized.* This phenomenon is explained in accordance with the emission theory, on the supposition that each luminous particle is endowed with poles—that, in polarized light, these poles are all turned in one way, and in opposite ways in the two beams; whereas, in common light, these poles are perpetually changing their direction. The explanation furnished by the wave theory is, that while common light consists of waves undulating in all possible planes, like those of sound, polarized light consists of waves, whose undulations are all performed in one plane, like those on the surface of water; and, in the case of the two separate beams, these single planes, in which the undulations are performed, are supposed to be perpendicular to each other. Moreover the undulations are, in either case, supposed to be perpendicular to the plane of polarization.

Light may be polarized not merely by its separation into two beams, in passing through a doubly refracting medium, but also by reflection from any smooth surface, at a particular angle, which is called the polarizing angle, and which always bears, to the refractive index of the medium, a constant relation. Polarization may also be effected by successive reflections from a polished surface at any angle. It may likewise be produced by transmitting the light through a succession of thin transparent plates. Light, polarized in one plane by refraction, may be brought into the opposite plane by reflexion, and *vice versâ.**

* This point is curiously illustrated by Wenham's binocular microscope. In that instrument the image reaches the right eye by refraction, and the left by reflection. Hence, on Nichol's prisms being applied, when the analyzer is placed behind the objective, the images, received by the two eyes, are found to be polarized in opposite

PLATE C.

FIG 1

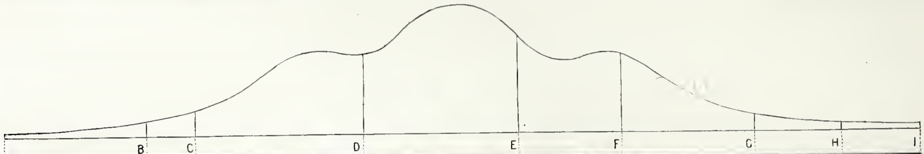


FIG 2

FIG 3

FIG 4

FIG 5

FIG 6

INTENSITY OF SPECTRUM.

Before leaving the subject of double refraction, it may be mentioned, that, in all crystals which exhibit this phenomenon, there are either one or two lines, along which the light may be transmitted, without being divided into two beams. These lines are called axes of double refraction. When a crystal possesses two such axes, and these considerably apart, as in Aragonite, and when a beam of light is transmitted along one of them in a careful manner, it is found to expand into a hollow cone of rays, which, when properly viewed, presents to the eye a beautiful luminous ring, of the form represented in Plate G, fig. 5. This phenomenon, which is called conical refraction, affords a great triumph to the wave-theory; for it was predicted from mathematical considerations, founded on that theory, by Sir W. Hamilton of Dublin, before it was actually ascertained to exist. Its explanation in accordance with the theory of emission does not appear to have been attempted; nor does it seem to be possible, without superadding to that hypothesis the idea of the luminous particles being preceded in their course by ethereal waves.

That the phenomena of double refraction are due to the circumstance of the media presenting them having different degrees of density, in different directions, is proved by the fact, that these phenomena may be artificially produced in transparent jellies, by subjecting them to pressure in various ways.

The phenomena which afford the most striking criterion by which to judge between the two theories, however, are those of shadows. These, at first sight, seem to be altogether in favour of the theory of emission; for the outlines of a

planes, and cannot be made to coincide. The only remedy is to remove the analyzer from behind the objective, and place an analyzer between each eye and its corresponding eye-piece, in opposite positions, so as to bring both beams into the same plane of polarization.

shadow are usually sharp and well defined, as they ought to be in accordance with that theory; whereas, according to the undulatory theory, the waves ought to bend round an obstacle, and so illuminate the interior of the shadow. These first appearances, however, are deceptive; for, if due precautions be taken, it will be found that the luminous waves do, in reality, thus bend round the edge of an obstacle, and so illuminate the interior of its shadow; while the absence of this effect, under ordinary circumstances, is owing to the obliteration of these internal waves from other causes—chiefly by the action of scattered light.

To show this phenomenon in its simplest aspect, light of *one* colour only should be admitted, through a small hole, into a dark chamber, and concentrated into a small focus, whence it may diverge freely. If, at a little distance from this focus, a wire, or a slip of card directed edgewise, be placed in the divergent beam, and if the shadow of this obstacle be thrown on a white screen, at some distance behind it, then it will be found that the light bends round the obstacle on either side, and illuminates the interior of the shadow. This light, however, appears, not as a continuous illumination, fading gradually off from the edge of the shadow, but in the form of several distinct alternations of light and shade, on each side, termed fringes, the centre being always light. Another similar set of fringes extends outwards from the edge of the shadow, on either side, so that the shadow exhibits both external and internal fringes—a phenomenon termed "diffraction"—the light being broken into two distinct parts, by each of the edges. (See Plate G, fig. 6.) That these fringes are not a mere optical illusion, but real physical alternations of light and darkness, is proved by the circumstance that their image may be fixed on a sensitive surface by photographic means.

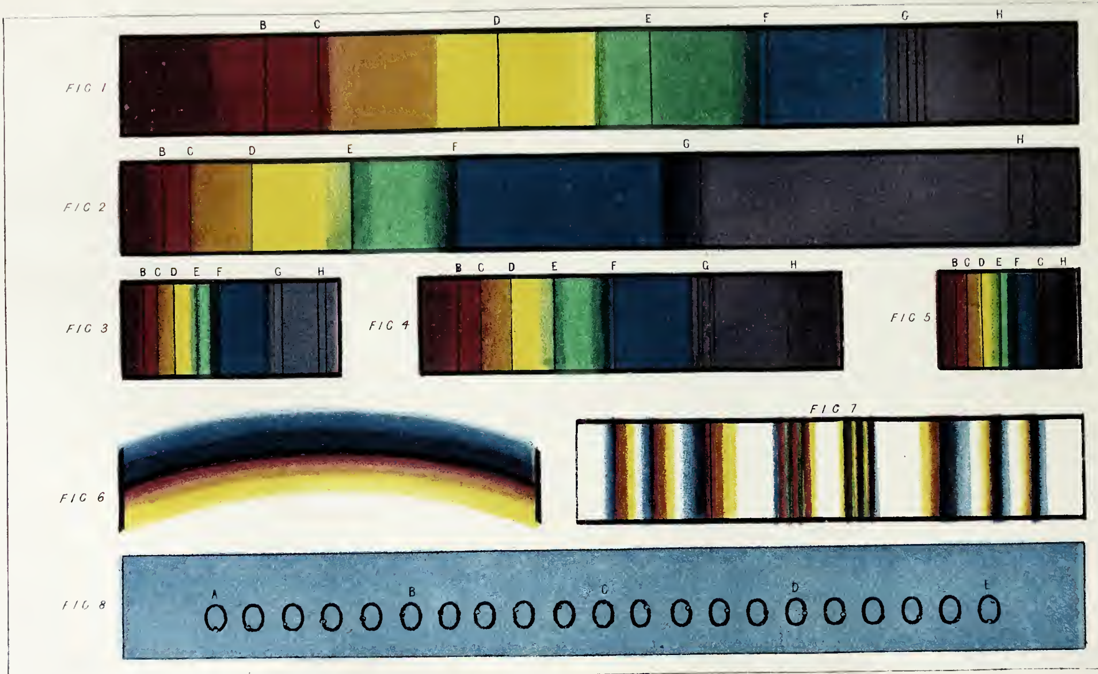
The most singular circumstance connected with them is, that to the formation of the *internal* fringes the co-operation of the light from both sides of the obstacle is indispensable. If the light passing one side be intercepted, the fringes disappear from both sides. The internal fringes are thus evidently due to the overlapping of these two lights. The explanation furnished by the wave theory is beautifully simple. The waves bent inwards on the one side, meeting with those bent inwards on the other, mutually interfere—alternately increasing and diminishing each other's effects—so giving rise to the alternations of light and darkness. The external fringes are due to a like interference of the waves coming directly from the focus, with supplementary waves, propagated outwards from the edge of the obstacle, as a new centre. But to explain this phenomenon, in accordance with the theory of emission, is exceedingly difficult. The bending inwards of the light cannot be accounted for by supposing the emitted particles to be attracted inwards by the edge itself; for the nature and extent of the phenomenon are alike uninfluenced by the nature of the edge. Nor would such a supposition account for the obliteration of the fringes, on both sides, by the interception of the light passing one of the edges. The only resource here left to the supporters of the theory of emission, is again to call in the aid of the conjecture, thrown out by Newton, to explain the fits of easy reflection and easy refraction—namely, that the emitted particles of light are preceded in their course by the waves of an invisible, elastic ether, and that, as these waves pass the edge of the obstacle, a portion of them is turned inwards, in accordance with the theory of undulations; while the emitted luminous particles, on subsequently arriving at the edge, are similarly wafted inwards by those waves. The fringes, formed on the recipient screen, are, according to this view,

caused by the arrival of the particles, in alternating fits of easy reflection and easy refraction, produced by the waves alternately accelerating and retarding the onward progress of the particles.

It will thus be perceived, that the supposition of an elastic ether is quite as indispensable to the theory of emission as to its rival, and that the question is, not so much respecting the existence of such an ether, as in regard to the part which it performs in the production of luminous phenomena. According to the one view, the undulations of this ether are of themselves alone capable of explaining all the phenomena; according to the other view, these undulations act only a subordinate part—altering or modifying, in various ways, the condition of the luminous particles during their passage through the ether. But it is a rule in sound philosophy, not to multiply causes without need; and seeing the existence of ethereal waves is a necessity in both theories, if these waves, viewed purely and simply, are of themselves capable of explaining the phenomena, it would be unphilosophical, without some absolute necessity, to introduce the additional agency of luminous particles emitted by the luminary.

Now, in the case of the particular phenomenon of the internal fringes on a shadow, the introduction of luminous particles rather embarrasses than helps the explanation furnished by the ethereal waves; for if, instead of using light of one colour, common sun-light be employed for the divergent beam, the fringes then display the beautiful and varied hues of the rainbow, and that in regular and symmetrical succession. (See Plate H, fig. 7.) This circumstance is readily accounted for by the wave theory, in which the colour of the light is dependent on the length of the ethereal wave, so that waves of different lengths must of necessity produce alternations of different colours, by the overlapping

PLATE H.



VARIOUS SPECTRA.

of various systems of waves. But according to the theory of emission, difference of colour is due to an essential difference in the emitted particles—there being red-making particles, and blue-making particles, &c.; and to explain the above phenomena, in accordance with this idea, it would be needful to suppose the red-making particles to propagate before them ethereal waves of greater length than those propagated by the blue-making particles, and that, on coming to the edge, each set of particles is wafted inwards only on those waves which are propagated by themselves, and not on those propagated by the other particles. All these constitute a most unnecessary accumulation of assumptions, seeing the phenomena can be quite well explained by the interference of the waves alone.

The explanation of the internal fringes, on the principle of the interference of waves, leads directly to the inference, that, when the obstacle is circular, instead of linear, the centre of the shadow will be as luminous as if no obstacle were present. This deduction is confirmed by experiment.

CHAPTER IV.

"And God divided the light from the darkness."—Gen. i. 4.

The beautiful principle of the interference of luminous waves, and the alternations of light and darkness thereby occasicned, may be exhibited in the following simple form:—Let one of the surfaces of a piece of thick plate glass be so ground as to present two faces very slightly inclined to each other, and to the unaltered face; and after having been re-polished, let one half of each of the inclined faces be silvered. Thus one half of the plate will form two slightly inclined mirrors, and the other half a transparent prism with a very obtuse angle. Covering up the transparent half, let light of one colour be concentrated in a small focus, in a dark chamber, and let the silvered glass be so placed in front of the focus, that the two images thereof which it forms may be thrown on the same point of a white screen. Here the two cones of light, thus falling on the screen, instead of producing an uniformly luminous circular disc, present a series of alternate bright and dark bands, parallel to the line of junction of the two mirrors. Now let the silvered portion of the plate be covered, and the transparent part exposed, the screen being at the same time removed to the side of the plate opposite to that from which the light comes. It will again be found that the circular luminous disc, produced by the coincidence of the two images, is similarly traversed by light and dark bands, lying in the same direction as before. That in either case, both images must conspire to produce these alternations, is proved by the disappearance of the fringes on either one of the mirrors in the first case, or one of the inclined

faces in the second being covered up. Now these two beams of light differ in no other particular than that of their having in each case passed through slightly different distances in travelling from the focus to the screen; and to no other cause than this minute difference of distance can the alternations of light and darkness be ascribed.

According to the theory of emission, the alternations would be explained on the supposition that the difference of distance alters the fit of the particles from one of easy reflection to one of easy refraction. On the wave theory, they are explained by the interference of the waves which have passed through different intervals of space. When the difference of distance is exactly equal to the length of a wave, or to any exact multiple of that length, the two waves, arriving at the same instant, conspire, and doubling the amplitude of the vibratory motion, quadruple the brightness of the light. But when the difference of distance is equal to half a wave, the two waves extinguish each other, and produce darkness. Hence the alternate bright and dark bands exhibited on the screen. It thus arises that the total amount of brightness, diffused over the space covered by the bands, is the same as if the light had uniformly overspread the surface.

These alternations may be displayed in a yet simpler way. Take two long strips of plate-glass, and insert between them, at one end, a small strip of tissue paper; then press both ends firmly with the fingers. View this combination by the light of a spirit lamp, with a salted wick, in a room otherwise dark, then the whole surface of the plates will appear covered with alternate light and dark lines. In this case, the alternations are produced by the light reflected by the one inclined surface interfering with that reflected by the other—the light from the further surface having travelled by a slightly longer path than that from the nearer.

If in either of the before-mentioned experiments, the colour of the light be changed, other circumstances remaining the same, it will be found that the breadth of the fringes is altered, being greatest when the colour is red, and least when it is violet. This phenomenon furnishes one of the methods by which the lengths of the waves, or of the intervals between the fits, may be determined. But by reason of the difficulty of procuring the light absolutely pure, and of one colour only, it is not the best mode of determination. Owing to the differences in the breadth of the fringes, produced by different colours, it happens, that when in the first of the above-mentioned experiments, sun-light is concentrated in the focus, the fringes present symmetrical coloured bands, instead of mere alternations of greater and less brightness.

It has been stated that these alternations are explained in accordance with the theory of emission, by supposing that the difference of the path traversed causes a change of fit; while in the wave-theory, it is due simply to the interference of the undulations. At this point, the important experiment of Arago, before referred to, comes into play as an arbiter between these two views. The central fringe is produced by the two beams, which arrive at the point where it appears in the same interval of time. Now, if one of the beams be either quickened or delayed in its course, by being made to pass through a thin plate of any substance, the position of the central fringe, and of the whole system, will be shifted. If the beam, passing through the interposed plate, be quickened in its speed, the central fringe and the entire system will be shifted *further away* from that side where the interposed plate has been applied. But if the beam, by passing through the interposed plate, have its speed slackened, the system of fringes will be shifted *towards* that side. Now, Arago ascertained by experiment that the

denser the interposed plate, and the higher its refractive power, the nearer were the fringes shifted *towards* that side at which the plate was applied, thus proving the light to be *retarded* in passing through the denser medium, in accordance with the wave theory, instead of being *accelerated*, as it ought to be, according to the theory of emission. So marked and so definite is this change of position in the fringes, that the interposition of tubes containing different gases has been found an excellent method of determining the refractive power of those elastic fluids.

Here again the theory of emission is involved in a difficulty, out of which even the superadded supposition of the emitted particles being wafted on the waves of an elastic ether, will not help it, so that the triumph must remain with the simpler theory, that the waves of such an ether are themselves purely and simply the causes of all luminous phenomena.

Such are the chief grounds on which philosophers have been led to prefer the undulatory theory of light to its rival. It only remains to endeavour to form some definite conceptions in regard to the nature and movements of the elastic ether, whose existence that theory presumes—to remove some difficulties which may arise in the mind with respect to it, and to trace the consequences deducible from the admission of this theory, on the great question of the everlasting permanence of the material universe.

CHAPTER V.

"Who coverest thyself with light as with a garment."—Ps. civ. 2.
"The light dwelleth with Him."—Dan. ii. 22.

There are not a few of the statements of Scripture which are true in a double sense—a spiritual and a physical. Of these the ascription to the Deity, contained in the words first above quoted, is a striking example. If the light here spoken of be regarded as moral and intellectual, it is true that with such light, the Divine mind is clothed as with a garment. Nay, it is elsewhere affirmed that God is himself light, and in him is no darkness at all, an expression which obviously applies to light in a metaphysical sense. But regarding light as a physical phenomenon, it is equally true that with such, or at least with its cause, the Deity invests himself as with a garment. God, viewed as an all-pervading Spirit, has chosen to associate with himself, in his omnipresence, the material medium, whose motions constitute the physical appearance, to which we give the name of light. "The light dwelleth with him." This truth, which modern science has placed on a secure basis, seems to have found admission into the minds of some of the ancient sages as a fixed idea, perhaps without their being able to assign any reasonable grounds for their belief. At least, the expression, "Thou coverest (or investest) thyself with light as with a garment," appears to involve the idea of that which causes physical light, partaking with the Deity in his infinitely extended presence. The same notion of boundlessness, in reference to the material cause of light and darkness, appears to be involved in the Lord's challenge to Job, when he asks him, "Where is the way where light dwelleth? and

as for darkness, where is the place thereof, that thou shouldest take it to the bound thereof, and that thou shouldest know the paths to the house thereof."

The demonstration of the universality and illimitability of the material cause of light as a physical fact, arises out of the establishment of the wave theory of light, from which it flows as a necessary consequence. The grounds on which it falls to be preferred to its once formidable rival, have been already set forth, and it now only remains to develop somewhat more fully the ideas which naturally flow from this preference. Light being, according to the undulatory theory, nothing more than minute wavy motions, propagated through an universally diffused elastic ether, it becomes needful to form in the mind some conceptions, both of the constitution of that elastic medium, and of the nature of those wavy motions by which it is affected.

To constitute elasticity in any medium, it is indispensable to suppose the existence of certain numerous centres, in which the elastic force resides—that these centres are placed at certain definite mutual distances, and that these distances are capable of being increased or diminished within certain small limits. But as we cannot conceive of any force whatever, be it attractive or repulsive, as being exerted by nothing, or by mere space, it is needful to suppose these centres of elasticity to be occupied by matter, endowed with the property of exerting the force, and that to any distance from its immediate centre of presence. Some philosophers regard these material centres of force as being distinct, exceedingly small, impenetrable, material particles, separated from each other by void intervals, greater than themselves, but still very minute. Others imagine it possible to conceive of the universal medium as possessing continuous, uninterrupted materiality, instead of consisting of particles separated by

intervals. According to the latter view, this continuous medium possesses innumerable centres of force, at definite distances from each other, and which are capable of mutual approach or separation, within certain small limits; but the distances between these centres, being not mere space, are occupied by matter, possessing the specific force in question, in a smaller degree than that in which it is developed in the centres. To this latter view, however, there is this great objection, that it fails to account for the force being thus accumulated in certain centres, and existing only in a modified degree in the intervals separating them. There is also a difficulty in conceiving how the centres of force should, under such circumstances, be capable of greater or less approximation. The other view, again, by confining the actual presence of the material particles to the centres, clearly accounts for the force being accumulated in these; while, by the supposition of void intervals, the capability of motion is equally well explained. All that is requisite is to suppose that the force extends *influentially* to an indefinite distance from its source. It is not of much consequence, however, to which of these views the preference be given, provided the other continues to be regarded as a possible alternative; and that of the particles and spaces being the simpler, and more easily comprehensible, it may be as well to assume it hypothetically.

On either supposition, an elastic medium might be constituted, whether the force developed in the centres were attractive or repulsive, provided always that the medium were infinitely extended. Without this latter condition, the constitution of the medium would be in a state of perpetual progressive change. Were the force attractive, and were there a limit of free space, beyond which the medium did not extend, then the outermost centres of attraction,

having no countervailing force acting upon them in the outward direction, would be continually attracted inwards, by the centres of attraction lying nearer the centre of the medium; consequently the individual centres of attraction would be continually approaching nearer and nearer the centre of attraction common to the whole. They would thus be in a continual state of mutual approximation. On the other hand, were the force repulsive, and were there a limit of free space beyond which the medium did not extend, then the outermost centres of repulsion, having no exterior countervailing force tending to repel them inwards, would be continually driven outwards into the free space beyond, by the combined repulsive force of the individual repulsive centres situated nearer the centre of the medium; consequently, all the individual centres of repulsion would be continually receding further and further from their common centre, and separating from each other more and more.

Now we have clear and distinct evidence that in the ethereal medium the individual centres of force are neither approximating towards each other nor mutually separating. This evidence is furnished by the constancy of the rate of speed with which light travels through the free medium, in whatever direction it proceeds, and from whatever source it comes, be it the sun, the remotest fixed star, or the still more remote nebulæ. Were the centres of force approximating, this speed would be continually diminishing, and were the centres of force separating, this speed would be continually increasing; but as neither increase nor decrease has been detected during the long time throughout which observations have been continued, it must be concluded that the speed of light in the free ether is invariable, and is never lowered, except by the presence of ponderable matter. Hence it of necessity follows that the ether must be infinite in its

extension; that the universe is a material *plenum;* and that the ancient philosophical proverb, "Nature abhors a void," is literally true.

It is thus demonstrated that the Deity has associated with himself, in his omnipresence, the material cause of light; consequently that the ascription, "Thou coverest thyself with light as with a garment," is true of physical as well as of intellectual light. This fact also gives a peculiar point to the Lord's challenge, "Where is the way where light dwelleth?" &c.—because the medium, whose motions are light, whose stillness constitutes darkness, is quite as much without limit as the presence of the Deity himself.

On the other hand, we have, in this physical fact, the best and most striking of all proofs of the unlimited presence of God; because the motions of the ether, being regulated by very peculiar and strictly mathematical laws, arising out of the relations subsisting between its individual centres of force, and the human mind being incapable of conceiving of the existence of laws without a lawgiver, the universal presence of the ether is itself a proof of the universal presence of a Law-giving Mind; and the light which comes to us from the nebulæ is a palpable evidence, not only that the Deity is present in those remote regions of the universe, but that he was present and acting there millions of years ago, seeing this witness of his activity has taken that enormous space of time to reach our eyes.

Some philosophers maintain it to be impossible for the human intellect to form to itself any idea whatever of what is absolutely infinite; but if human reason can demonstrate the existence of a physical infinite, the human mind must be capable of forming *some sort* of idea of an infinite. The idea, indeed, will be *indefinite*, but it may, nevertheless, be *correct;* for what is infinite can never engender a *definite*

idea even in an infinite mind, indefiniteness being of the very essence of infinity, insomuch that a definite idea of what is infinite would be erroneous. In like manner, the reasoning faculty of one human mind can logically demonstrate, to the rational apprehension of another, the necessary existence of an Infinite Mind, and the human intellect may form certain very accurate conceptions with respect to the qualities or attributes of such an Infinite Mind; but all the ideas thus formed will of necessity be *indefinite*, for if definite, they would be *incorrect*. The general proposition, therefore, that a finite intellect can form no idea whatever of what is absolutely infinite, is inaccurate. The true form of the proposition is, that what is absolutely infinite cannot beget a definite idea in any mind, be it finite or infinite. But an idea, though indefinite, may be correct; and a definite idea formed with respect to what is absolutely infinite would of necessity be false.

As an illustration of this point, it will be remembered that the relation of the circumference of a circle to its diameter is expressed by the number 3, followed by a decimal fraction, which may be extended without limit. Were any one, therefore, to endeavour to form to himself, or convey to another, a definite idea of the relation which the circumference of a circle bears to its diameter, such an idea would be false. But if he should say that the number of times which the length of the circumference of a circle exceeds that of the diameter is greater than 3·141,592, but less than 3·141,593, the idea thus conveyed, while indefinite, will nevertheless be correct.

So, of any infinite whatever, be it mental, material, or abstract, the human intellect may form to itself certain ideas which are correct, so far as they go, while the notion of the *entire* of what is absolutely infinite remains quite indefinite,

as it must of necessity be, even in an infinite mind. For, in the above numerical example, it would be as impossible for an infinite as it is for a finite mind to specify what is the *last* figure in the decimal fraction, seeing that no figure whatever can ever be regarded as the last.

By far the greater part of our knowledge, indeed, is indefinite and incomplete, even where the object contemplated is finite. Perfect knowledge is confined to a few elementary abstract truths. We say that we know a man, when we can distinguish him from every other individual. Yet our knowledge is in this case extremely incomplete, for we could not be said to know him thoroughly, unless we knew not only every thought that had ever passed through his mind, but also every material atom composing his physical organism. Yet our inability to attain this perfect knowledge would not justify our affirming it to be impossible for a man ever to know any of his fellow-men. In like manner, our inability to grasp the infinite, or to know an infinite being in his infinitude, does not warrant the averment that we can have no knowledge of the infinite; for our knowledge of the infinite Deity is not essentially more qualified and imperfect, than is our knowledge of our fellow-men, or of any external object however finite it may be.

Calderwood, in his *Philosophy of the Infinite* (2d ed. p. 88), says,—" Our faith in an infinite being has no reference whatever to any infinite extension." But surely, if it can be shown that matter is infinitely extended, this fact must influence our ideas of the infinite mind, which gave laws to that infinitely extended matter. An infinite effect must have an infinite cause. The ubiquity of the ether demonstrates the divine presence as pervading all extent; and it appears impossible to divorce the idea of universal presence from that of universal extension. Pope seems to be nearer the truth in saying

of the Infinite Being, "that He extends through all extent."

Universal presence and continuous duration are the two attributes of the Divine Being to which the term infinity can be most properly applied. It is impossible to imagine power to be unconditioned or infinite, for we cannot conceive of an Infinite Being as possessing a power of self-annihilation. It is in like manner impossible to imagine knowledge as unconditioned or infinite, for knowledge cannot embrace an infinite number. The knowledge of the last term of an infinite decimal fraction is impossible, as exemplified in the instance above adduced. Hence infinity, or the absence of limit, cannot be absolutely affirmed either of power or knowledge. There is a similar limitation in all our conceptions of the moral attributes which we ascribe to the Deity. Our idea of his goodness and love is conditioned by our belief in the eternal punishment of the irreclaimably perverse—our idea of his absolute volition, by our knowledge that certain created wills are continuously opposed to his will—our notion of his justice, by our confidence in his mercy; and so on. It is thus doubtful whether human reason really does conceive of any of the divine attributes as being absolutely unconditioned, save his continuous self-existence and universal presence, nor could we have any absolute proof of this last attribute apart from the demonstration of the infinite extension of the ether.

CHAPTER VI.

"The light that goeth forth."—HOSEA vi. 5.

HAVING now obtained, with respect to that infinite ethereal medium, "whose centre is everywhere, and whose circumference is nowhere," an idea which, while of necessity indefinite, is nevertheless sufficiently correct, let us next endeavour to acquire some clear conceptions in regard to the nature of those wavy motions by which it is agitated, and which cause in us the perception of light and colours. In treating of this subject, the medium shall, for the sake of simplicity and precision, be regarded as consisting of impenetrable material particles, separated by minute intervals, although the same reasoning may be applied to the other view, of the perfect material continuity of the medium, substituting for the particles mere centres of elastic force.

It is very nearly impossible for the human intellect to unravel the complexity of these motions, unless the attention be confined to those performed in a single plane, as in the case of polarized light, and even then a careful analysis is requisite for giving precision to our ideas. The waves of the ether have been sometimes compared to the vibrations of an extended string or musical cord, or in the case of polarized light, to the waves on the surface of water; but these furnish mere analogies rather than accurate resemblances.

The best mode of illustrating these motions, regarded as confined to one plane, is to bring material points situated in the horizontal plane into a state of mutual repulsion, and then carefully to watch their behaviour when impulses are communicated to one or more of them. A convenient method

of effecting this object is the following:—Obtain a pretty large piece of soft iron plate, burnished on both sides, and let it be placed on a frame supported on four rather tall strong pillars, the frame and its supports being either of wood or brass, but not of iron. On the upper surface of the plate, and at regular small intervals, place a number of bar magnets in the perpendicular position, with their marked poles downwards, and in close contact with the plate, supporting the magnets in any convenient manner. By this arrangement the whole of the soft iron plate will have pretty equably diffused over it magnetism of one kind. Let a large number of equal sized sewing needles be now magnetized, so that the magnetism of their points shall be of the kind opposite to that developed in the plate, the eyes corresponding to the marked poles of the bar magnets. Let these needles be now suspended from their points by being allowed to attach themselves to the lower surface of the soft iron plate at nearly equal intervals, say from an eighth to a quarter of an inch apart. The needles will thus hang with their eyes in a state of mutual repulsion, and nearly in one plane. Those nearest the edge of the plate will not hang quite perpendicularly, but will be turned outwards, from the influence of the unbalanced repulsion of those nearer the centre, but this tendency to oblique suspension will decrease towards the centre of the plate. These needle-eyes will thus be in a state of mutual repulsion, somewhat resembling that subsisting among the particles of the ether, lying in one horizontal plane.

If now a similarly magnetized sewing needle be held between the fingers, by the point, and if the eye-end be suddenly approximated to any one of the outer rank of the suspended needles, and again rapidly withdrawn, it will be seen that the motion thus communicated to the individual needle will be immediately propagated to all the others. It not

only runs along the whole line of needles lying in the direction in which the impulse was given, but those on either side of that line also begin to move, so that the motion spreads both forward and laterally. The phenomena will be similar, if the needle held in the hand be rapidly passed between two of the suspended needles, instead of being made to approach directly towards one of them.

To study these motions thoroughly, it is needful to proceed by degrees. Take first the case of a single needle, suspended with its eye downwards, and let another needle, held in the hand, be suddenly approached towards it and withdrawn from it. As the two eyes repel each other, the suspended needle will be driven from the perpendicular, but will seek to return to it again, on the other needle being withdrawn. It will not come to rest at once, however, but will continue to oscillate at a certain rate and for a certain time. Let the suspended needle be now broken in half, the oscillations will then be more rapid, and will continue for a shorter time. If the remaining portion be again halved, the oscillations will be still further quickened, and rest still sooner attained; and if we could suppose the needle reduced to the mere point, the oscillation would then be quickest of all, and rest soonest regained. We have therefore from this analogy no reason to suppose that, were the repulsive particle indefinitely small, the motion imparted to it by any single impulse would be otherwise than of exceeding rapidity, and extremely short duration.

If, when the suspended needle is entire, and the motion is imparted to it by a similarly magnetized needle, the nature of the curve, described by the lower end of the suspended needle be carefully examined, it will be found to be an ellipse, unless it can be so contrived as to cause the direction of the impulse to pass directly through the axis of suspension

which it is exceedingly difficult to do. In this case the motion would be rectilinear, but in all other cases the path described is an ellipse, the relation of the major to the minor axis depending on the direction of the initial force, so that the ellipse lies between the limits on the one side of a right line, and on the other side of a circle.

When the impulse is single, however, the orbit alters its form; the repelled extremity of the needle first takes a sweep away from its point of rest, and then returns, by a succession of gradually diminishing ellipses, to its point of rest, the returning path being thus an elliptical spiral. But if the impulse be renewed at regular intervals, then the elliptical orbit may be maintained for any length of time. It is only when thus maintained that it presents a useful analogy to the motion of the ethereal particles; for the movements communicated to the latter by a single impulse are too transient to be made the objects of study. The only effect produced on the particles of the ether by a single impulse, that can be rendered palpable, is the extreme brevity of its duration.

To elucidate this point, let a spoked wheel be put into a state of exceedingly rapid rotation, so that, when viewed by ordinary light, it appears like a continuous disc; and, all other light being excluded, let it be momentarily illuminated by a single magnetic spark, the wheel will be seen only for an instant, and will appear as if standing perfectly still. This fact shows that the undulations communicated to the ether by a single impulse do not continue for any appreciable length of time.

Another fact may be rendered evident by the magnetic spark. If the observer turn his back to the point from which the spark is emitted, and look on a printed page illuminated by its light alone, it will be found that, if a succession of

sparks be produced, the aspect of the printed page will vary with the rapidity of this succession. If the rapidity exceed ten sparks in a second, the page will remain continuously visible; and any increase of rapidity will merely increase the brightness of the illumination; but if the rapidity be less than ten in a second, the page will alternately disappear and reappear at intervals corresponding to those of the emission of the spark. It may be hence concluded, that the effect produced on the optic nerve by a single impulse continues for about a tenth of a second; that ten such impulses in a second suffice to produce continuous vision, but that 100 or 1000 in a second will correspondingly increase the brilliancy of the luminous effect.

Now suppose that, instead of one needle, a very great number are suspended at equal intervals in a single straight line. It will be seen that, as soon as the first in the line begins to move, the motion commences to travel with great rapidity along the whole line; and it would continue so to travel were the line prolonged indefinitely, provided the needles moved without friction on their points, and without resistance from the air. Now, if the line of moving needles be carefully scrutinized, it will be seen that the position of the individual needle-eyes in their respective orbits differs. Suppose the major axis of the elliptic orbit to be across the line in which the needles are arranged, and the minor axis along that line, and imagine the observer so stationed as to view the line from one side. Let him note the instant at which the first needle-eye in the series is at the point of the major axis of its orbit next to him. He will then perceive that the second is a very little removed from that point, the third a little further, and so on, till he comes to one which is at the point of the minor axis of its orbit, or a quarter of a revolution behind the first. Still further on he will find

one which is at the extremity of the major axis of its orbit furthest from him, and so half a revolution behind the first. He will find again, further on, one that is three quarters of a revolution behind the first; and he will at length come to one which is at the same point of its orbit as the first. Now the distance between the first and this last corresponds to the length of a wave, or undulation. It is the distance which the motion travels along the line of needles during the time occupied by any single individual needle-eye, in performing one revolution in its orbit. These different points of the orbit are termed phases. When two of the needle-eyes are at the same extremity of the greater axis of their respective orbits, they are in the same phase. When they are at opposite ends of the greater axis, they are in opposite phases; and when one is at either extremity of the greater axis, and the other at either extremity of the lesser axis, they are in intermediate phases. Hence, while the distance between two which are in the same phase is reckoned an entire undulation, the distance between two which are in opposite phases is reckoned half an undulation, while the distance between one which is at the extremity of the major axis of its orbit, and another which is at the extremity of the minor axis, is counted as a quarter of an undulation. This last corresponds to a Newtonian fit.

This subject will be better understood by reference to Plate H, fig. 8, where the line A B C D E corresponds to the direction of propagation or axis of undulation. The white dots represent the ethereal particles, and the black ellipses their orbits, only these are, for the sake of distinction, greatly magnified in size and reduced in number, in comparison with the wave-length, which, however, is also highly magnified—nearly 250,000 times. The distance from A to E, at which two points the particles are in the same phase, is an entire

wave-length. The distances A C and C E, at which points the particles are in opposite phases, are half wave-lengths; while the distances A B, B C, C D, D E, at which points the particles are in intermediate phases, are each a quarter of a wave-length, corresponding to a Newtonian fit. It will be perceived from this figure that the perpendicular height from A the hollow, to C the crest of the wave, is identical with the greater axis of the orbit of each particle involved in the wave-motion.

To obtain a distinct idea of polarization, it is only necessary to lay this figure first in the horizontal plane, in which case the direction of the wave-motion and the planes of the orbits of the individual particles, will correspond to what subsists when light is polarized in the vertical plane. If the figure be next held vertically, the wave motion and planes of the orbits will correspond to what subsists when the light is polarized in the horizontal plane.

From the foregoing, it follows that the length of the undulation is always reckoned in the direction in which the initial impulse is propagated from particle to particle in a right line. It also follows from the above, that, in any system of particles placed at equal intervals in a straight line, and mutually repelling each other, the motion communicated to any one will be propagated along the whole line, and this to infinity, provided the particles are free to move without friction. It will thus be easily understood how, in the case of the ether, whose particles are mutually repellant, and have perfect freedom of motion, without friction, the impulse travels onward in a right line for ever. This right line may be termed "the axis of undulation," or "principal line of propagation," and corresponds to the direction of a ray of light.

It is needful to keep clearly before the mind the distinction

between the orbital motion of each individual particle and the wave motion. In the former, the particles themselves move, but do not progress. Their motion is performed about a fixed point, and at a very minute distance from that point, to which they always return when the moving force ceases to act. In the undulation, again, it is not the particles, but their motion that progresses. There is no transfer of matter from point to point of space, but merely a transfer of motion; and as long as the motion continues to be supplied, it will persevere in travelling onwards, from particle to particle, for ever.

The direction in which the wave motion thus travels is altogether independent of the direction of the greater axis of the orbit of the individual movement of each particle. To make this plain: instead of imparting motion to the first in the line of suspended needles by means of a similarly magnetized needle, let motion be given to it by touching it, at regular intervals, with a fine hair. Let the impulse be applied first in the direction of the line, so as to make the first needle move to and fro, as nearly as possible in a straight line in that direction. It will be seen that the whole of the needles will imitate this motion, and perform the same sort of oscillation. Let the impulse be next applied so as to make the first needle move as nearly as possible in a straight line at right angles to the line of propagation. Still each needle will imitate the motion of the first, and this transverse movement will travel onwards in the same manner as did the longitudinal movement. So, if we can contrive to make the first needle move as nearly as possible in a circle, each of the needles in the line will describe the same curve. Certain luminous phenomena require us to suppose that, in the case of light, where the orbit traversed by the individual particles is not circular, the longer axis of

the ellipse is at right angles to the principal line of propagation. The individual vibrations are then said to be *transversal* to the principal line of propagation, the orbit being either elliptical or rectilinear. It is obvious, however, that whenever the orbit is not absolutely rectilinear, there is motion of the individual particles both along the line of propagation and transversely to it, although the latter may predominate. To this rule, however, there is an exception—namely, when the plane of the orbit is perpendicular to the line of propagation; in which case the motion must be altogether transverse to the axis of undulation, whatever may be the form of the orbit. This case may exist in the instance of the ether, but it would be difficult to represent it by any analogous motion produced by mechanical means. It is easy to see, however, that the direction of propagation would be as independent of the direction in which the orbitual motion is performed as in the case where the plane of the orbit lies in that of the axis of undulation.

To the single line of suspended needles let there be now added other four—two on either side of the first line—and let the first in the central line be made to vibrate as before. It will be found that the motion now travels not only along the principal line, but that the other two lines are similarly affected—the needle-eyes in these imitating the motions performed by those lying in the central line. Were these lateral lines now to be extended in number, so as to make the number of lines on either side of the central line equal to the number of needles in that line itself, and were the impulse, as before, communicated to the first needle in the central line, it would be found that the motion would reach all the points equally distant from the disturbed needle at the same time. Thus, any line may be selected as the line of propagation, and any individual needle which is performing an

orbitual motion may be considered as the centre of motion with respect to all the rest.

If the motion, instead of being imparted to one needle only, be communicated similtaneously to several, at some distance from each other in the first rank, it will be seen that the lateral motions are arrested midway between the lines to which these needles severally belong, because of the countervailing forces; so that the motion originating with any individual needle is unable to spread itself far laterally. But this does not in any way interfere with its propagation in the forward direction.

It is this last case that presents the closest analogy to that of the particles of the ether, where, in every case which can be subjected to observation, the principal lines of propagation are very numerous; so that the motions transmitted laterally from those axes of undulation must interfere with one another and neutralize each other's effects, without, however, interfering with the propagation in the direction of the axes themselves. If these principal axes of motion, however, diverge rapidly from each other, the lateral motions will spread themselves more and more from the axes. This case of divergent axes of undulation is always presented near a focus, or any very small source of light; and as the undulatory motion travels to an equal distance from the first disturbed particle in all directions in equal times, it follows that the axes of undulation starting from each point are the radii of a sphere. Were these axes very limited in number, the supplementary lateral motions, generated on all sides of the axes, would develop themselves more and more as the undulatory motion progressed onwards along the principal axes. But in all cases the axes are so numerous as to prevent this development from being observed, except under particular circumstances. Thus, the undulatory motion is

always compelled to develop itself more in the direction outwards from the centre than in any direction at right angles to that one.

In the case of light coming from a distant source, the axes of undulation diverge so slightly that they may be always regarded as parallel; and the undulatory surface, although, strictly speaking, a portion of a sphere, yet differs so little from a plane touching the surface of the sphere, that it may always be regarded as identical with such a tangent plane. Hence, the luminous waves are, for the most part, regarded as plane waves—that is, presenting a plane surface to the spectator—and the axes of undulation are, for the most part, regarded as parallel.

Although, in the case of suspended needles, the axis of undulation has been regarded as consisting of a single line of needles, it does not follow that this is really the case with the particles of the lumeniferous ether; because it is probable that the atoms of ponderable bodies greatly exceed in size the particles composing the ether. So that, when the motion of the ethereal particles is excited by any orbitual movement of the individual atoms of a ponderable body, it is not ununlikely that a considerable number of ethereal particles are affected and put in motion at the same instant of time. Each principal axis of undulation may accordingly comprehend several lines of ethereal particles, moving with exact simultaneousness. It will also be perceived how, in this manner, the axes of undulation may be generated in very rapid succession by a swift motion of the ponderable atom through the ether, whether progressive or gyratory, or both.

When observations are made on the luminous waves near the centre whence they proceed, and where the axes of undulation diverge rapidly from each other, it is obvious that, were an obstacle interposed so as to stop a portion of these

axes, those on either side of the obstacle will be free to develop the lateral motion already described. Each particle in those axes of undulation which graze the obstacle, will become a fresh centre of propagation, from which the undulatory motion will be propagated into the ether on either side; and it is to the lateral supplementary waves thus propagated that the phenomena of diffracted fringes, already described are to be attributed.

CHAPTER VII.

"And the Spirit of God excited tremors on the aspect of the fluids; and God said, 'Be light,' and it was light."—Gen. i. 2, 3.

From the above quotation, which is a perfectly fair mode of rendering the original Hebrew text, it might be legitimately inferred that the sacred writer had in his mind an idea that light consists of tremors or vibrations in a fluid medium. His intention appears to have been to intimate that these vibrations were at first excited by a special energy put forth upon the fluids by the divine Spirit, and that God constituted this tremulous motion the cause of light. Indeed, it is difficult to assign any intelligible meaning to this excitement of tremors on the aspect of the fluids, unless we connect it with the subsequent averment, that God said, "Be light," and it was light,—meaning that the tremors which his Spirit had aroused should constitute light.

Bearing in mind the distinction between the vibratory motion, or the orbitual movement of each individual particle of the lumeniferous ether, and the undulatory motion, which consists in the transfer of the orbitual movement from particle to particle, in any particular line of direction, it is now requisite to attend to the part performed by each of these two motions in producing the phenomena of light. In a general view, then, it is to the orbitual motion that are due the phenomena of mere *brightness*, or of luminous intensity; while it is to the undulatory motion that are due the phenomena of *colour*, which depend on the orbitual motion only in so far as that regulates the undulatory motion.

Confining attention first to the mere brightness, it is regarded as depending on the amplitude of the orbitual motion —that is, on the extent to which the individual ethereal particle is driven from its point of rest by the moving force, or, in other words, on the diameter of the orbit which the particle describes. When these orbits differ in diameter, the degree of brightness produced is directly proportional to the squares of the amplitudes. Thus if an orbit of a given amplitude produces a certain degree of brightness, an orbit of twice the amplitude will produce four times the degree of brightness, and one of three times the amplitude, will produce nine times the degree of brightness, and so on.

It is the orbit of the particle situated at the *recipient* surface, and not that of the particles at the surface, whence the motion proceeds, that regulates the brightness. In the case of direct vision, the particle at the recipient surface is that by which the optic nerve is immediately excited to action; but when the light is received on a screen, as in the case of the diffracted fringes, the surface of the screen may be regarded as the recipient surface. Thus it may happen, that the motion, travelling along two distinct axes of undulation which meet in one point, may excite at that point a different amount of orbitual motion from any subsisting in the axes themselves. If the motion arrive at the point of intersection in such a manner that the particle situated at that point is simultaneously urged in the same direction by the two forces, the orbit of this particle will have double of the amplitude of that of any of the particles situated in either of the two axes themselves; consequently the brightness will be four times greater than what would be produced by either of the axes acting alone. But were the motion coming along the one axis to arrive at the interval of half an undulation behind

the other, the effect produced by the first would be obliterated by the second, and, instead of an increase of brilliancy, there would be produced darkness.

It is by accumulating the united forces of the motions, travelling along many axes of undulation, in a single point, or in a very small space, that what is called a focus of illumination is produced. In such a focus the ethereal particles are excited to move in orbits of far greater amplitude than do any of the particles lying in the individual axes of undulation. Owing to the action of the crystalline lens of the eye, which has the power of collecting numerous axes of undulation, and directing them upon a very small surface, the optic nerve is always agitated by ethereal particles, the amplitude of whose vibrations is due to the concurrent action of many axes of undulation. So also by artificial lenses, this effect may be very greatly increased.

Again, as it has been shown that impulses, reaching the optic nerve at intervals of one-tenth of a second, are sufficient to maintain continuous vision, it is obvious that were the rapidity increased a hundred or a thousandfold the orbitual motion of the ethereal particle, which immediately acts on the optic nerve, might be raised to a far greater amount of amplitude; so that movements, which are individually of small amount, by succeeding each other with great rapidity along any axis of undulation, might produce an impression of intense brilliancy on the optic nerve. This will be readily understood when it is borne in mind that in a tenth of a second the luminous impulse travels 19,500 miles, and that impulses separated from each other by this vast interval suffice to maintain continuous vision. How great then would be the effect on the optic nerve were the impulses only an inch apart, and renewing their action at correspondingly short intervals of time? It is in this manner that we may explain

the intense impression of brightness which may be produced by placing small lights in a straight line behind one another, and allowing their united impulses to reach the eye lengthwise. Hence it is also, that at a given distance from a gas burner of the flat form the greatest brightness is obtained from the edge, and not from the flat side of the burner.

There are thus two distinct causes to which the amplitude of vibration, and consequent brightness at the recipient surface, may be due,—the one the union in a single point, or at least within a very small space, of many distinct axes of undulation,—the other the arrival at the recipient point of a multitude of distinct impulses, along any given axis, in extremely rapid succession. Hence the brightness at the recipient point does not enable us to judge of the nature and extent of the initial forces, but merely of the effect produced by those forces at that point.

We are thus led to distinguish between the *intrinsic* and *adventitious* intensity of the light proceeding from any luminous source. The *intrinsic* intensity, or the capability of each separate axis of undulation to excite a given amount of vibration at the recipient surface, will depend on the number of successive impulses travelling along each individual axis of undulation in the tenth of a second of time; but the *adventitious* intensity will depend on the number of these axes of undulation which are brought to bear on a given point of the recipient surface within the same space of time. Now, when the light proceeds from a central source, these axes of undulation form the radii of a sphere; and the recipient surface, at any distance from the centre, must form a portion of the surface of such sphere. But as the surfaces of spheres are to each other as the squares of their radii, it follows that the quantity of motion distributed over any such surface must vary as the square of the distance from the

centre; consequently the *adventitious* intensity of the light must also vary as the square of the distance from the luminous source.

The amplitude of the individual vibration, and the length of the undulation which it produces, are mutually independent; consequently the brightness and the colour are, in like manner, independent. It is otherwise, however, with the rapidity of the individual vibration; for it is on this that the length of the undulation directly depends. The length of the wave is simply the distance traversed by the moving force, along any axis, during the time occupied by any individual particle, lying in that axis, in performing a single complete revolution in its orbit—the motion travelling at the rate of 195,000 miles in a second. Now, the lengths of the undulations can be determined with great accuracy; consequently the number of revolutions in its orbit, performed by any individual particle in a second, can likewise be determined; for it is the same as the number of wave-lengths, to which the vibration gives rise, embraced in 195,000 miles. There being on an average about 50,000 wave-lengths to every linear inch in the free ether, it follows that the number in 195,000 miles is between 617 and 618 billions; which is accordingly the average number of revolutions in its orbit performed in a second of time by each ethereal particle involved in the wave-length.

While some vague notion may thus be formed of the rapidity of the individual vibrations, we have no criterion by which to judge of their actual amplitude. This much appears certain, that, as there is no progression of the particles of the ether, from point to point of space, but each particle has its allotted point of rest, to which it always returns when it ceases to be agitated by any external force, we must conclude, that no one particle can ever be driven so

far from its own point of rest, as to pass into that of another. Indeed, it can never be so far removed from its appointed position, as to be nearer to that of another, than to its own; for the mutual repulsion of the particles would prevent such an excess of departure. Thus, the utmost limit of distance, to which any particle can be driven from its point of rest, is half the distance which separates it from its neighbouring particles. The limit of amplitude is thus involved in the question of the number of ethereal particles included in the length of a luminous wave. Now, although it is impossible to ascertain this number with our present means of inquiry, yet it is possible to show that it cannot be less than a certain amount.

The usual thickness of gold-leaf is such, that there are about 400,000 leaves to the inch. In this condition gold is translucent, and imparts to the light, which passes through it, a tint of green. This translucency continues, even when the light passes through three or four leaves of the above thickness. Professor Faraday has found that, when gold-leaf is spread out on glass, and kept for some time at a temperature equal to that of boiling oil, and then allowed to cool, the tint of the transmitted light is changed from green to ruby red. But on pressure being applied, the gold-leaf is restored to its original condition, and the tint of the transmitted light again becomes green. This change is obviously owing to an alteration in the state of aggregation of the molecules of gold, comprised within the thickness of the leaf. In the ordinary state of gold-leaf these molecules are so aggregated as to constitute a lamellar structure. But when the leaf is heated, this lamellar structure appears to be lost, and the molecules pass into a state of looser aggregation, from which they may be brought back into the lamellar condition by mere pressure. This change of tint thus be-

comes an evidence that the thinnest gold-leaf embraces, within its thickness, a considerable number of molecules of gold, it being by an alteration in the arrangement of these, that the change of colour is produced.

Now, Professor Faraday has succeeded in obtaining films of gold so thin, that he computes 350,000,000 of them could be embraced within an inch; consequently, 7000 of them within the average length of a luminous wave. But these very attenuated films exhibit the same change in the tint of the light passing through them, as does ordinary gold-leaf. After they have been subjected to the requisite temperature, the tint of the transmitted light becomes ruby red, but by simple pressure it is restored to green. It is hence evident, that even these very thin films must embrace, within their thickness, a considerable number of molecules of gold, in order that, by a change in their state of aggregation, this remarkable alteration of tint may be produced. It thus appears that, within the average length of a wave of light, the number of golden molecules embraced must be several times 7000.

Now, when any ponderable substance, such as gold, is introduced into any portion of the ether, the *mass* of the ponderable body does not displace a corresponding *mass* of the ether, as a solid body displaces a mass of air. It is only the *individual molecules* of the ponderable mass, that displace the *individual particles* of the ether, which thus become more approximated together, in the interstices between the gravitating molecules of the solid. The action is thus nearly the same as when one gas is mixed with another, as in the instance of the oxygen and nitrogen gases of the atmosphere, in which the two gases mutually subsist, in the interstices between the molecules of each other. From this it follows, that, in any given space occupied by the ether,

when a solid body is introduced, the same quantity of ether remains there as before, only in a state of compression, corresponding to the number and size of the atoms of the intruding body. Thus, in the thickness occupied by a film of gold, there are present, at any given instant of time, the same number of ethereal particles, whether the gold be there or not. The only difference is, that, when the gold film is present, the ethereal particles exist in the interstices between the molecules of gold, and so are forced into greater proximity to each other. Now, as it has been shown, that, in films of gold, of which there may be 7000 embraced in a wave length, there must be several golden molecules, separated by intervals containing the elastic ether, (seeing the vibrations of the individual particles of the ether are affected by the state of aggregation of these molecules), it is plain, that the number of the ethereal particles must exceed that of the golden molecules. It is thus demonstrable, that the number of individual orbits of vibration in the ether, embraced in a luminous wave length, must be several times 7000; but in the present state of our knowledge, we are unable to assign any ulterior limit, or specify any number within which that of the individual orbits of vibration, embraced in a wave length, must fall.

CHAPTER VIII.

"And his brightness was as the light."—HAB. iii. 4.

BRIGHTNESS, it has been shown, depends on the extent to which each particle of the ether, involved in a luminous wave, is removed from its point of rest; and certain facts have been adduced to prove how very minute, in any case, this departure must be. From these facts it appears that the mutual proximity of the particles or centres of elasticity of the ether must be such, that the diameter of any individual orbit of vibration must bear an exceedingly small proportion to the length of a wave; and this circumstance creates an apparent difficulty, connected with the undulatory theory. For, as the brightness of the light depends on the amplitude of the vibration, it appears difficult to imagine how the orbits, if they go on diminishing from the centre of agitation, do not speedily become reduced to nothing; seeing their magnitude must, at the outset, be so very small. Yet we find, that light, which has been travelling from a luminary so distant that thousands of years have been occupied in the journey, still exhibits such an amount of amplitude in the individual vibrations, as suffices to agitate the optic nerve. But this objection is founded on the assumption, that the amplitudes of the individual orbits, in any single line of propagation, do actually diminish as the motion travels onwards, from particle to particle,—an assumption for which there is no ground. For of the brightness, or amplitude of vibration, we can form no judgment, except as it exists at the recipient surface, whether that be the retina of the eye, or the surface of a sensitive plate. Now, the amplitude, at

the recipient surface, has no necessary relation to the amplitudes of the individual orbits, in any single line of propagation, or axis of undulation; for it depends, in the first place, on the number of distinct impulses, travelling along any given axis of undulation, within a tenth of a second; and, secondly, on the number of these axes, which are concentrated on a given point—this latter being the most powerful regulator of the amount of brightness, or of amplitude of vibration at the recipient surface.

To illustrate this point, let the moon be examined through a moderately sized telescope, which will admit the whole disc of the luminary in the field of view. The moon will then appear very considerably brighter, than if it be viewed with the naked eye. But reverse the telescope, turning the eye-piece towards the moon, and looking through the field-glass; and the luminary will now appear as if removed to a great distance, and much diminished in brightness. Here the individual lunar rays undergo no change. They pass through the same number of glasses, and there is nothing in the alteration of the position of the instrument, which can affect either the amplitude of the individual vibrations, or the succession of impulses travelling along any line within the tenth of a second. The difference of brightness is caused solely by a difference in the number of rays, or of axes of undulation, brought to bear upon a given surface of the retina. When the telescope is directed, in its right position, towards the moon, a larger number of the rays is collected by the field-glass, and concentrated by the eye-piece, on a definite surface of the retina. The amplitude of the individual vibrations of the ethereal particles, which immediately act on the retina, is thus increased; and hence the augmentation of brightness. When the telescope is reversed, the action is also reversed; a smaller number of lunar rays,

received by the eye-piece, is by the field-glass directed on a definite surface of the retina; the amplitude of the individual vibrations, at that surface, are thus diminished; consequently the perception of brightness is much weakened. But the individual vibrations in the lunar rays themselves, and the length of the waves, remain unchanged; so that the waxing and waning of brightness is, in this case, caused entirely by the increase and diminution in the number of rays, received on a definite surface of the retina.

If the telescope be now, by daylight, directed to a not very distant house, the phenomena will appear somewhat anomalous. If we look at the house with the right eye through the telescope, and with the left eye naked, the portion of the surface seen by the right eye will be very much smaller than that seen by the left, but this smaller portion will appear magnified, and as if brought nearer to the eye. There will, however, be hardly any perceptible difference in the brightness of the impression made on the two eyes. If the telescope be now reversed, the entire house will appear to the right eye to be removed to a great distance, and much reduced in size as compared with what it appears to the left eye. But the brightness of the image seen by the right eye will greatly exceed that of the image seen by the left, in so much that the image formed on the right will appear like a small bright spot on the image seen by the left eye. Thus, in this case, the brightness is increased by the reversal of the telescope; whereas, in the case of the moon, it was diminished by that reversal. Yet, here again the whole effect is due to the difference in the number of the rays falling on a given surface of the retina. When the telescope is used in its right position, the rays coming from the small portion of the house within the field of view are gathered together, and directed by the instrument on the retina; but

the left eye receives the rays coming from a much larger surface of the house, and the two impressions are thus rendered nearly equal in brightness—the right eye, by means of the instrument, receiving nearly as many rays from the small surface which it sees, as the left eye receives from the larger surface which it embraces within its field of vision. But when the telescope is reversed, the rays from the entire house are brought to bear on the right eye, while those from only an inconsiderable portion of the house fall on the left; and hence the impression of brightness is stronger on the right eye than on the left. The increase of illuminated surface brought within the field of view more than compensates for the diminished number of rays coming from any limited portion of that surface, whereas, in the case of the moon, there can be no such compensation, seeing no greater amount of illuminated surface is brought within the field of view. In the case of the house, as in that of the moon, the individual rays coming from the house are unaltered, either as respects the amplitude of the individual vibrations, the number of impulses travelling along any given line within the tenth of a second, or the length of the waves. Yet, the impression of brightness made upon the retina by these rays can be altered in the manner above described, merely by an increase or diminution in the number of rays, or axes of undulation, concentrated on a given point of the retina.

It is thus manifest that the impression on the retina has no direct dependence on the amplitudes of the orbitual vibrations in any individual axis of undulation, consequently we have no proof that these amplitudes decrease while the distance from the origin of the motion increases, like the amplitudes at the recipient surface. On the contrary, the very circumstance, that the individual vibration, travelling along any axis, although so small in comparison with a wave-length,

may yet, after having travelled myriads of years, be capable, if a sufficient number of these axes be collected and brought to bear on a given surface of the retina, of there exciting a vibration of sufficient amplitude to produce the perception of considerable brightness, appears in itself sufficient evidence that the amplitude of the individual vibrations in any single axis of undulation undergoes no diminution as the motion recedes from the point of its origin, but remains as constant as does the length of the wave propagated along that axis.

It has been stated that the amplitude of the vibrations, by which the sensation of brightness is produced, is altogether independent of the length of the wave to which is due the perception of colour; for the brightness may vary much while the colour remains constant, or *vice versa*. This, however, is true only of the amplitude of the vibration at the recipient surface, and does not apply to the amplitude of the individual orbits of vibration, whose motion is transferred from particle to particle along any line of propagation; for it is quite possible that there may be an intimate relation between the amplitudes of such orbits and the time in which the particle describes a single revolution in its orbit, which again regulates the length of the wave. Thus, in the case of the remarkable change in the tint of the light passing through films of gold above mentioned, it seems pretty evident that the alteration from red to green, which is effected by mere pressure, is due to the diminution in the individual amplitudes. The individual vibration being slower in the red light than in the green, the gain in rapidity consequent on the approximation of the molecules of gold caused by the pressure, must be obtained at the expense of the amplitude of the orbit, seeing the applied force—that of the vibratory motion of the incident light—remains the same. When the molecules of gold are loosely aggregated, the particles of

ether entangled in their interstices have room to perform larger vibrations than when those interstices are reduced in size, consequently the motion is slower, and the length of the wave generated longer; but when, by the diminution of the interstices, the particles are obliged to perform their motions in smaller orbits, while the motive energy remains the same, the motion becomes quickened, and the length of the wave generated is shorter. It thus appears that an alteration in the amplitude of the individual vibrations in any single line of propagation may affect the rate of vibration, the wave-length, and the colour, which last depends entirely on the length of the wave.

CHAPTER IX.

"I do set my bow in the cloud."—GEN. ix. 13.

To produce any visual impression at all, the length of the luminous wave must lie between certain very definite limits; if it be either longer or shorter, it fails to affect the optic nerve. In like manner, to produce the distinct impression of any pure colour, the length of the wave must lie between two still more circumscribed limits. The longest waves generate a very deep, but not bright red, known as the extreme red. The shortest produce a violet, verging on lavender, known as the extreme violet. Between these lie other five, well-defined, pure colours—orange, yellow, green, blue, and indigo,* the wave-lengths corresponding to them being in the order of their enumeration. To compose white light, these different colours must be mingled in certain fixed proportions; and it is a matter of extreme difficulty to hit these proportions with such exactness as to form white by artificial means. In sun-light, however, these proportions subsist in the utmost perfection; and when it is considered that this effect is produced merely by the combination of waves of different lengths, it must be regarded as an extraordinary example of wise adaptation of means to an end, that, in the light destined to serve as the universal cause of vision for our planet, so nice an adjustment should be found. The effect is similar to that produced on the ear by the harmony of a perfect chord, when a tonic is sounded with its third, fifth, and octave, only the number of elements entering into the combination is greater.

* The colour is nearly that of *sublimed* indigo.

White light may be decomposed, and its constituent colours presented to the eye, by several means. The most perfect mode of accomplishing this object is first to bring the light into a very fine *linear* focus, whence it is allowed to diverge. Then a plate of parallel glass is to be obtained, on one of whose faces have been engraved, with a sharp diamond point, very numerous equi-distant fine lines, so close that there may be from 10,000 to 30,000 to the inch. This plate is to be placed at some distance behind the focus, with the engraved lines parallel to the line of the focus, the surface of the plate being so adjusted that the extreme lines are equi-distant from the focus. The plate is then to be viewed through a small achromatic telescope, the engraved side of the glass being next the spectator, and all other light being carefully excluded from the apartment. In this manner is formed what is called the diffracted spectrum, first discovered by Fraunhofer. The spectrum thus obtained is of exceeding purity, the edges of the different colours being sharply defined, provided due care has been taken in the ruling of the fine lines, to secure their being exactly equidistant from each other. This spectrum is represented it Plate H, fig. 1.

As regards brightness, it is found that the brightest point in this spectrum is exactly in the centre, whence it decreases on either side symmetrically. The curve representing the rates is one of double flexure, there being, after the first diminution, a slight increase, followed by a more rapid decrease. See Plate G, figs. 1 and 2.

The most striking phenomenon, however, presented by the diffracted spectrum is the appearance of numerous fine dark lines, parallel to the bands of colour, and traversing them lengthwise. The total number of these lines is very great; but Fraunhofer selected seven, which exhibit certain marked peculiarities, rendering them easily distinguishable from the

others, and which are known as the fixed lines of the spectrum.* These he designated by the seven letters B, C, D, E, F, G, H. B is in the red, near that extremity of the spectrum; C also in the red, but on the confines of the orange; D in the yellow; E in the green; F in the blue; G in the indigo; and H in the violet. These lines are shown in the figures above referred to. They form standard points in the spectrum, their positions may be determined with great accuracy, and they are consequently of much value in optical investigations. These particular lines, however, are seen only in light originally derived from the sun; but they are found in it, whether it be taken directly from that luminary, or be first reflected either from a terrestrial object, or from the moon, or any of the planets. If the light be derived from any other source, as from a fixed star or any artificial flame, the system of lines is wholly diverse from that found in solar light—each species of light being distinguishable by its own peculiar system of lines. It is very remarkable, that in the electric light, obtained from electrodes of carbon, there are seven lines nearly corresponding in position to the seven principal lines of the solar spectrum; but instead of being dark, they are brighter than the rest of the image. By means of these lines, then, solar light can always be distinguished from every other kind.

Fraunhofer was at great pains to determine with precision the wave-lengths corresponding to the seven principal lines; and he has left on record two sets of numbers, which agree exactly as regards B and D, but differ slightly as regards the others, most of all with respect to H—thus showing that there are limits of accuracy beyond which observation can-

* M. Kirchhoff, by employing a much more dispersive apparatus and higher magnifying powers, has discovered many more lines than those detected by Fraunhofer, and has resolved into groups several of the lines which previously appeared single.

not go. The values thus determined were for long considered as independent, unrelated quantities; but it has recently been shown that they are so related to each other by certain definite laws, that the wave-length of B being given, according to any standard of measurement, those of all the other lines may be deduced from it, by a simple calculation founded on those laws. The numbers thus found differ from the observed quantities less than the two sets of these differ from each other. Assuming the wave-length of B as unity, the proportional wave-lengths corresponding to the other lines, as deduced by these laws, are represented by the following decimal fractions: C=0·953291, D=0·855626, E=0·764331, F=0·706140, G=0·623944, H=0·573248.*

The wave-length of B, in decimal parts of an English inch, is nearly 0·0000271; and that of the others, according to the same standard, may be found by multiplying this quantity by the above decimal fractions.

The next characteristic of the diffracted spectrum is, that the wave-length of the red extremity is exactly double of that corresponding to the violet extremity, so that these two stand to each other in the same relation as a musical tonic does to its octave. The colours in this spectrum are all pure, the coloured light being incapable of further decomposition. The lines of junction of the colours are also sharply defined, and the wave-lengths corresponding to these lines of junction bear to the wave-lengths of the extremities the same relation as the notes in the musical scale bear to the tonic. Assuming the wave-length of the red extremity as 1, those of the others are represented by the following decimal fractions: 0·88′, 0·833′, 0·75, 0·66′, 0·6, 0·5625′, and 0·5. The length of the mean wave is also mathematically related to that of the others, and would, in the above series, be repre-

* See *Phil. Mag.*, Oct. 1860.

sented by the decimal fraction 0·77′. Hence, if the length of the mean-wave, or that of either of the extremes, be given, according to any particular standard of measurement, those of all the others may be found.

It is only in the diffracted spectrum, however, that these relations and characteristics subsist.

The second method of decomposing white light and forming a spectrum is by transmitting a divergent beam through a prism, instead of passing it through a system of fine equidistant lines. The spectra, thus obtained, are never pure, and vary in appearance and characteristics, both with the angle of the prism and the nature of the substance of which it is formed. For the purpose, therefore, of comparing with each other the spectra given by prisms of different substances, it is needful to have the inclination of the two faces of the prism, through which the light passes, constant, and the distance of the prism, on the one hand, from the luminous focus, and on the other hand, from the telescope fixed.

When the spectra produced by different media are examined under such circumstances, and compared with the diffracted spectrum, the first peculiarity arresting attention is the variation in the distance between the red and violet extremes, owing to the difference in the dispersive powers of the media. Amongst those of lowest dispersive power is water, which accordingly gives a very short spectrum; amongst those of high dispersive power, oil of cassia is one of the most remarkable, its spectrum being of great length. If the several spectra be examined, as regards the brightness of the different parts, it will be seen that the greatest brilliancy is no longer exactly in the centre, as it is in the diffracted spectrum; neither is the curve by which it decreases on either side from the brightest point symmetrical; but both

the position of that point and the form of the curve differ in the spectra produced by different media. The curve formed by the gradations of brightness in the spectrum produced by flint glass is shown in Plate G, fig. 3, and the corresponding gradations of shade in fig. 4. The lines of junction of the various colours are never so well defined in these prismatic spectra as in that obtained by diffraction; but the colours gradually shade off into each other. What is still more remarkable, the breadths of the coloured bands no longer bear to each other the same proportions as they exhibit in the diffracted spectrum. On the contrary, these proportions vary exceedingly in different media, a phenomenon termed the *irrationality*. This departure from the standard proportions of the colours is least in the case of sulphuric acid, and greatest in the case of oil of cassia.

With respect to the fixed lines of Fraunhofer, their positions are much affected by the irrationality, their mutual distances varying in the different spectra from the standard exhibited by the diffracted spectrum; and this is one of the most interesting phenomena presented by these various spectra; because, owing to the degree of precision with which the positions of these lines can be determined, the changes in their mutual distances, consequently in their refractive indices and the corresponding wave-lengths, can be made the subject of mathematical research. From such an investigation, it has been found that these changes are governed by very peculiar and beautiful laws—that in all cases, the waves corresponding to the fixed lines undergo a slight retardation or acceleration involved in the irrationality, viewed as distinct from either the refractive or dispersive powers of the medium, and that these retardations and accelerations have certain definite relations.

The coloured spectra produced by oil of cassia, crown

glass, flint glass, and water, are shown in Plate H, figs. 2, 3, 4, 5, in their relative proportions, with the positions of the fixed lines in each. These may be compared with their positions in the diffracted spectrum fig. 1, which is magnified to the size of the oil of cassia spectrum.* Fig 6 shows the introverted spectrum produced by viewing the horizontal bar of a window through a glass prism. In this case the image of the bar is bent into an arch, the red and violet of the spectrum are brought into conjunction, the yellow and blue are thrown to the extremes, and the green is wanting. This arrangement is the same as in the first of the fringes of a shadow.

The natural spectrum—the rainbow—is due to the refraction of the sun's rays through falling rain-drops. To produce this phenomenon, it is necessary that there be a bright sun opposite to a dark cloud, whence rain is descending. The solar rays, passing through the rain-drops, are reflected from their hinder surfaces, and thence again transmitted to the eye of the spectator. They undergo refraction and dispersion during both these transmissions, and thus become separated into their coloured elements.

* These figures show merely the degree in which the lines are displaced generally by the refracting media, but not the degree in which the displacing power affects each line. To do so would require greater space. In all prismatic spectra there are, as afterwards more fully explained, two nodal points, at which the displacement is *nil*. Between these two nodes the displacement is opposite to what it is on either hand beyond them. To compare any refracted spectrum, then, with the standard spectrum obtained by diffraction, it is needful to ascertain the two nodes, which can be easily done by calculation. The refracted spectrum being then laid down on paper with the nodes marked, the diffracted spectrum is to be laid down along side of it, making the distance between the nodes the same, and inserting the fixed lines in their proper positions with reference to these nodes. Then the alteration of position of all the fixed lines will at once appear. Thus, in the case of the oil of cassia, the line G should be nearly opposite the same line in the diffracted spectrum, and the distance between G and C made nearly the same in both. Then the true displacements of the other lines would be rendered manifest.

CHAPTER X.

"Behold he spreadeth his light."—JOB xxxvi. 30.

IT appears from what has been said, that there are three distinct phenomena presented by the prismatic spectrum: 1st, The refraction, by which the waves generally are more or less diverted out of their course, in proportion to the state of compression of the ether within the pores of the medium; 2d, The dispersion, in virtue of which the waves, producing the different colours, are refracted in different degrees, and consequently more or less separated from each other, this being the prime cause of the colouration of the spectrum; and 3d, The irrationality, in virtue of which the proportions of the different colours, and the mutual distances of the fixed lines, are altered from what they are in the diffracted spectrum, and that in various manners in the spectra produced by different media.

Although in a very general view, media which have a high refractive power have also a high dispersive power, yet to this rule there are exceptions so many and so great, as to show that these two powers are quite independent of each other. For example, the refractive power of the oil of cassia is inferior to that of crown glass, but the dispersive power of the former greatly exceeds that of the latter. It thus becomes possible, by combining different media, to obtain refraction without dispersion. Such combinations are termed *achromatic*, and are of great use in the construction of optical instruments. For example, as flint glass considerably exceeds crown glass in dispersive power, the dispersion produced by the flint glass may be made to correct or neu-

tralize that of the crown, while yet a considerable portion of the refractive power of the latter remains available. As the amount of dispersion varies, not only with the medium, but also with the inclination of the faces of the prism, it is also possible, by combining prisms having very different inclinations, but formed of the same material, to obtain refraction without dispersion; and by means of such combinations, achromatic optical instruments may be formed of one kind of glass.

Confining attention, in the first instance, to the dispersive and refractive powers, and supposing the medium to have no irrationality, but that the proportions of the coloured spaces, and the mutual distances of the fixed lines, remain as in the diffracted spectrum, it is not difficult to trace the action of these two powers alone. In all ponderable media, the ether is more compressed than it is in the great ethereal expanse; the particles, or centres of elasticity, are forced into greater mutual proximity. Now, the undulatory motion, arising from a given amount of primary disturbance, would, in the absence of any other interfering force, affect in its progress the same number of ethereal particles in the same space of time, so that the nearer these particles are approximated, the slower will be the progress of the motion in the direction of propagation. For example, suppose the distance between the particles, situated in any right line, to be by compression diminished in the proportion of eight to five; then if, in the free ether, the progressive undulatory motion travelled an inch during the time occupied by each individual particle, in performing 50,000 revolutions in its orbit, then in the compressed ether, it would, to travel an inch, require the time occupied by each individual particle in performing 80,000 revolutions in its orbit. Hence it appears that, according to the undulatory theory, compression of the ether involves re-

tardation of the progress of the undulatory motion; and it can be mathematically demonstrated that such retardation involves change of direction, on entering the compressed portion of the medium obliquely—thus giving rise to the phenomenon of simple refraction. It is plain, however, that the effect of mere compression on the waves of different length must be rateable; so that, were this cause operating alone, we should always have refraction without dispersion. This condition may be produced artificially, by combining a flint-glass prism with one of crown-class; and we shall then have a dilatation of the image, caused by refraction, but no colour. In this case, the effect is due to the compression of the ether alone.

It is thus rendered obvious that dispersion, or the separation of the waves having primary different lengths, is due, not to the mere compression of the ether, but to some special action of the ponderable molecules of the medium on the particles of the ether, momentarily entangled in its pores. Nor is it difficult to divine what the nature of this action is likely to be. In the free ether, each particle has a certain amount of persistence in its appointed position, caused by the forces which all the other particles exert upon it. When the particles are forcibly approximated, this persistence is proportionally augmented by the increased intensity of the forces, consequent on the diminution of distance; and it is to this increase of persistence that the shortening of the waves is due. But if the ponderable molecules of the medium, which causes the compression, exert on the ethereal particles forces stronger than those which the latter exert on each other, it is evident that the ethereal particles will, from this cause, acquire a greater amount of persistence in their appointed positions, than they gain from their greater mutual proximity alone. It will hence arise, that the undulatory

motion of each wave will embrace, in its length, a smaller number of ethereal particles than what is due to it in the free ether; so that, besides the shortening which the wave undergoes from the mere proximity of the particles embraced in its length, it will suffer a further shortening from a diminution in the number of those particles themselves. Thus each wave, in passing through the medium, loses a certain definite number of the particles, which, while the wave is passing through the free ether, are embraced in its length; and the number thus lost being the same for all waves, the shorter waves sustain, from this cause, a greater *proportional* loss of length than do the long waves—the rateable curtailment being in inverse proportion to the length of the wave. Now, the shortening of the wave being equivalent to an increase in its refractive index, it thus happens that, on entering the medium obliquely, the waves of different lengths become refracted in different degrees, and pursue different paths; so that, if the face of emergence be inclined to the face of entrance, the waves, on emerging, become separated from each other, and that to a degree proportionate to the amount of this peculiar force which the medium has exerted, tending to increase the persistence of the ethereal particles in their places. Hence the dispersion of the waves, and the impression of different colours which they produce.

There is thus in all media a certain index of refraction, which, being common to all the waves, indicates the state of compression of the ether in its pores, and may therefore be regarded as the index of elasticity of the ether within the medium. But when the wave-lengths, as they exist in the free ether, have been reduced by being divided by this index, they have to be still further reduced, by having a certain quantity taken from the length of each wave, which quan-

tity, while varying with the medium, is constant for all the waves, and is the cause of their separation. It may, therefore, be termed the constant of dispersion. These two quantities—the index of elasticity and the constant of dispersion—are mutually independent, insomuch that a high index of elasticity may consist with a low constant of dispersion, and *vice versa.*

The wave-lengths obtained in this manner, however, are only such as would subsist, were there no *irrationality* in the spectrum produced by the medium—that is, if the proportions of the different colours, and the mutual distances of the fixed lines, bore to each other the same relations as they present in the diffracted spectrum. But almost all refracted spectra exhibit more or less of this irrationality, manifesting itself in a displacement of the fixed lines by an alteration of their mutual distances. Different media exhibit this phenomenon in very diverse degrees, and under various modifications. The manner in which the individual fixed lines are affected by this displacing force, is at first sight very capricious; but on careful examination, it will be found that while the individual displacements seem very irregular, their mutual relations are nevertheless governed by certain remarkably beautiful fixed laws. On a general view, the displacement always takes place by the retardation of the extreme waves being increased at the expense of that of the central waves, so that the extreme waves appear *more,* and the central waves *less* refracted, than they would be by the refractive and dispersive forces acting alone, the increments and decrements in the resulting lengths of the waves exactly balancing each other. Hence it arises that in every spectrum exhibiting irrationality there are two nodal points, at which the irrationality is *nil*—the one situated in the immediate vicinity of the line G, the other between the

lines C and D, and occupying nearly the position of the mean wave. The waves lying between these two nodal points are all longer, while those lying beyond the nodes, on either extreme, are shorter than they would be were the refractive and dispersive forces acting alone.

It is worthy of remark, that this distribution corresponds very nearly to that of the degree of brightness of the spectrum, consequently of the amplitude of the individual vibrations in the different waves. The force, whatever it may be, which causes the phenomenon, operates with proportionally less effect on the waves whose individual vibrations have the greatest amplitude. Hence it would appear to be a force exerted by the ponderable molecules of the medium, in virtue of which the amplitudes of all the individual vibrations are diminished by a certain definite amount, so that the larger amplitudes are reduced in a lower proportion than are the smaller. This diminution will, as we have seen, be accompanied by a corresponding increase in the rapidity of the individual vibrations, consequently in the refractive index of the wave. Experiments are wanting on the comparative brightness of the different parts of the refracted spectrum produced by each medium, in order to ascertain what is the precise relation between the irrationality and the distribution of the brightness, and thus to determine how far the former is dependent on the latter, and whether the above explanation be correct. In the meantime, all that can be affirmed with certainty is, that the ponderable molecules of the medium exert on the ethereal particles a certain influence, which alters the rate of their individual vibrations, and thus indirectly affects the length of the wave. This influence may possibly be of the nature of that sympathy which subsists between oscillating pendulums of nearly the same length, and vibrating musical strings, which give nearly the same note.

The total amount of the irrationality may be estimated by adding together the sums of the amounts by which the extreme waves are shortened beyond their due proportion, and the amounts by which the central waves are shortened less than their due proportion. This sum total varies very much in different media, and in the same medium at different temperatures, as do also the index of elasticity, and the constant of dispersion. The oil of Cassia is the medium which exhibits the greatest amount of irrationality, while sulphuric acid presents the least. The amount of the irrationality has no direct dependence on either the index of elasticity, or the constant of dispersion, but may vary indefinitely in its relation to these two quantities. Nevertheless these three—the index of elasticity, the constant of dispersion, and the total irrationality—are so connected together, that, if the whole three be known, then, by the application of certain determinate laws, and by means of formulæ founded on these laws, the indices of refraction corresponding to all the fixed lines, as also that of the mean wave, may be calculated with great accuracy. In order to ascertain these three quantities correctly, it is well to have observations made on all the seven fixed lines with as much accuracy as possible; the subsequent application of the formulæ being required only to correct the results derived from observation, and bring them under the dominion of the determinate laws. The case is similar to that of the successive observations by which the orbit of a planet or a comet is determined. The actual observations usually give more or less of a zig-zag path, which has, by the application of the formulæ, deducible from the law of gravitation, to be reduced to a continuous symmetrical curve. So, in the case of the refractive indices of the fixed lines, the values given even by the best observations are merely approximations more or less perfect to the

truth; but from these approximations the true values may be determined by the application of the formulæ founded on the laws. Furthermore, the laws are of such a character that if the refractive indices of two of the extreme lines and one of the middle lines be *very accurately* determined by experiment, then those of the other four may be ascertained by calculation as correctly as by observation.

CHAPTER XI.

"As the appearance of the bow that is in the cloud in the day of rain, so was the appearance of the brightness round about."—Ezek. i. 28.

One of the most puzzling points connected with the spectrum is the relation between the brightness and the colour, or, in other words, between the amplitude of the orbits in which the ethereal particles move, and the rapidity with which the motion is performed. It has been stated that in the diffracted spectrum, the amplitudes are greatest at the centre, and diminish symmetrically on either side; whereas the rapidity of the orbitual motion increases regularly from the red to the violet extremity; and the refracted spectra differ only as respects the position of the point of greatest amplitude. It thus appears that on either side of this maximum point there are vibrations of equal amplitude, performed in very unequal times—those on the red being slower than those on the violet side. Hence the amount of motive energy must be greater in the half of the spectrum that lies on the violet side of the point of greatest amplitude, than in the half that lies on the red side. The only way of accounting for this difference is to suppose that the ponderable molecules originating the vibrations differ in their mode of action on the ethereal particles. That the action of the ponderable molecules is concerned in the production of light of different colours, is rendered evident by the phenomena of coloured flames. Thus salts of strontium and lithium produce red flames, salts of sodium yellow, salts of copper and barium green; sulphur gives a blue flame, salts of potassium and tincture of iodine a violet. In all these cases

the rate of rapidity of the orbital motion of the ethereal particles appears to be regulated by the nature of the ponderable molecules by which the action is excited; but the brightness or amplitude is governed by the violence of the chemical action. Thus the brightness of all the coloured flames may be greatly enhanced by burning the inflammable materials in oxygen gas, instead of atmospheric air, while the tint of colour remains unchanged. *Here* the increase of amplitude at the recipient surface is evidently due to an increase in the rapidity with which the impulses succeed each other in any individual line of propagation, and in the number of these lines propagated within a given area in a given time, but not to any increase in the amplitudes of the individual vibrations travelling along those lines. Hence it is probable that, in the case of the spectrum, the increase of brightness towards the centre, and its symmetrical fading off towards either side, are due not to any difference in the amplitudes of the vibrations travelling along the individual axes of undulation, but either to a difference in the rapidity with which the separate impulses succeed each other along those axes, or more probably to a difference in the number of axes collected and exerting their influence at the different parts of the spectrum. Either of these causes will sufficiently account for the increase of brightness towards the centre of the spectrum, without resorting to the supposition that, as they start from the luminous source, the vibrations travelling along different axes differ in their amplitude as well as in their rapidity. We may on the other hand regard the whole of the vibrations coming from any luminous source as having at starting the same amplitude, and as differing only as respects their rapidity, which increases from the red to the violet, the motive energy increasing in the same direction.

The probability of this view is strengthened by the phe-

nomena attending incandescence, or the rendering a body luminous by the simple application of heat, but without combustion. When a body first becomes incandescent, the larger proportion of the rays belong to the extreme red of the spectrum. As the temperature increases, the colour becomes what is known as the cherry red; it thence passes through orange into yellow, and lastly into a dazzling white. What is very remarkable is, that these changes are independent of the nature of the substance employed, and are produced solely by the increase of temperature, insomuch that the colour of the light is a pretty correct index of the degree of heat by which it is produced; with this exception, however, that permanent gases cannot be rendered incandescent. It thus appears that a lower amount of motive energy is required to generate the red and yellow rays, than what is needed for the production of the green, blue, and violet rays, which are necessary for the constitution of white light.

That the heat in this case acts simply as a motive force is evidenced by the fact, that pure white light can be obtained without sensible heat. If the rays of the moon be collected into a focus by a very large polyzonal lens, the focus will become as luminous as a disc of equal size raised to a white heat; the light will be equally white, but the rise of temperature will be inappreciable. So also in the case of the phosphorescence of the ocean, where the motive energy originates with microscopic animalcules. There the light is pure white, showing that all the degrees of motive energy required for the production of the different colours are brought into play; but there is no sensible rise of temperature. The impression of brightness at the recipient surface is in this last case exceedingly feeble, because the number of impulses generated in the tenth of a second is scarcely beyond what is required for maintaining continuous vision, while the number

of axes of undulation which can be brought to bear upon any point of the recipient surface is very small. Yet by very greatly increasing the latter quantity a considerable amount of brightness may be obtained. The colour is also white and independent of temperature, or even of outward luminous impression, in another remarkable case. When one has been asleep in such a position as to produce a certain amount of pressure on the head, if on awaking the eyes be opened, there will be seen as if on the wall of the chamber a bright image, which will continue perceptible for a considerable time, and then gradually fade away. To exhibit this phenomenon, the room must be perfectly dark. In this case the effect is probably due to the pressure on the head, which excites the optic nerve, and thus produces the same perception as would be induced by external vibrations exciting the expanded fibres of the nerve spread over the retina.* This phenomenon shows that there is a natural tendency in the optic nerve to vibrate in such a manner as to induce the perception of whiteness, or of mere brightness without colour, and that the perception of colour may be regarded as, to a certain extent, an exceptional condition.

The phenomena of colour blindness lead to the same conclusion. To a person labouring under this peculiar defect of vision, the constituents of white light appear to be quite

* The author has enjoyed frequent opportunities of studying these singular phenomena. In his case the spectral illusion has sometimes the appearance of an indefinite brightness, but more frequently there is a distinct image formed on the bright ground. The most common image is that of a human face and bust; but sometimes it is that of the head of an animal, as of a horse or bull. On one occasion the image resembled a beautiful flower, like a red hyacinth considerably magnified. This last was the only case in which the image was colonred. In all other instances it presented only pure light and shade. It is not improbable that this species of spectral illusion has given rise to the many floating stories about apparitions and ghosts, more especially when the image assumes the appearance of the human countenance. The descriptions commonly given of ghosts correspond exactly with the aspect of these spectral images. But of the many faces which the anthor has observed in these spectres, there has never been one that he could recognise as having previously seen in the flesh.

different from what they are in a healthy eye. It is remarkable that the insensibility of the nerve in these cases for the most part begins with the red, in which the rapidity of vibration is slowest, consequently the amount of motive energy weakest. To such persons all reds appear black; and it might therefore be naturally inferred that a white surface should appear not white, but what white would be with the red abstracted from it. Yet this is not the case; the perception of whiteness is never wanting. Indeed in some cases the absence of the perception of colour goes so far, that the eye is sensible only of light and shade. It hence appears that to the perception of colour there is required a peculiar and perfect adaptation of the optic nerve to receive distinct impressions from the vibrations of different and definite degrees of rapidity. The case somewhat resembles that of a musical and non-musical ear. The latter hears the musical notes, but does not appreciate their differences. They are all regarded alike as mere noise.

Thus the *rates* of orbitual motion in the ethereal particles are determined by the movements of the ponderable molecules with which the motion originates—the less energetic of these movements producing those slower ethereal vibrations which cause the perception of red—the more energetic molecular movements originating those quicker ethereal vibrations which awaken the perception of violet. But the *amplitudes* of the vibrations as they exist, not at the recipient surface, but in the individual lines of propagation themselves, must in a great measure depend on the room which the ethereal particles have for the performance of their excursions; or, in other words, on the degree of tension in which the ether is held. These amplitudes will consequently be greatest in the free ether, where the tension is lowest, and they will be least in those media which exert

the greatest amount of compressive force on the ether, so confining the spaces within which the vibrations fall to be performed. The increase of brightness, therefore, observed in the central portions of the spectrum are to be traced, not to larger amplitudes of vibration existing in the individual lines of propagation which occupy that region, but either to the circumstance that the impulses succeed each other more rapidly along those lines, or to the accumulation in that region of a greater number of individual axes of undulation. Of these two causes the latter appears the more probable, because it is the more simple. For it would be difficult to assign any reason for the succession of impulses being more rapid along the central lines than along the extreme lines; whereas it is easy to conceive that the vibrations, whose rate is intermediate between the two extremes, should be produced in greater abundance than are either the very slow or the very quick, and that there should consequently be a greater accumulation of distinct axes of undulation in the central portion of the spectrum, so giving rise to large amplitudes of vibration at that part of the recipient surface.

The mere visual phenomena of the spectrum, then, do not of themselves afford sufficient proof that in the vibrations, as they exist in the free ether, there is any difference of amplitude. On the other hand, the increase of heating power from the violet to the red extremity of the solar spectrum, and even beyond the latter point, shows that there is an increase of *somewhat* in that direction, which counteracts the decrease in the rapidity of the vibrations, as regards their effect on the ponderable molecules of bodies. This phenomenon may be accounted for in one of two ways. The increase of heating effect may be due simply to the circumstance that the slower vibrations, acting for a longer time on the ponderable molecules, tend more effectually to generate or augment in these

that species of vibration which constitutes temperature; or the vibrations may increase in amplitude regularly as they diminish in rapidity, and this increase may be manifested by their augmented power of exciting the tremours of temperature. But if the latter alternative be preferred, we must suppose the increase in amplitude, after passing the central point, to be counteracted by a rapid diminution in the number of the individual axes of vibration in order to account for the decrease of brightness towards the red extremity.

From the circumstance that, in the diffracted spectrum, the coloured spaces have definite and considerable breadths, while these breadths vary in the refracted spectra produced by different media, it appears that the adaptation of the optic nerve to receive distinct impressions of colour from vibrations of different rates, is restricted within certain limits. There are rates of vibration and lengths of waves differing considerably from each other in reality, but between which we cannot distinguish by the eye, so that they create the impressions of the same tint of colour. In the diffracted spectrum, the limits between the colours are sharply defined, but when, by the dispersive power of refractive media the rays bordering on two colours are considerably separated, then the eye receives impressions from a greater number of those waves in which the vibrations are of intermediate degrees of rapidity, so that our judgment is puzzled, and we are at a loss, with respect to the tint, to which we should assign them. There hence arises an apparent blending of the colours, and it becomes difficult to determine by the eye where one colour ends and another begins. We may not, from this circumstance, infer, however, that there are vibrations of the *same* degree of rapidity which produce *different* impressions of colour, although it be true that the same impression of colour may be produced by vibrations which

differ very considerably in their rapidity. The apparent blending of the tints does not arise from a true admixture of rays, but from a defect in our judgment of the impression which certain rays produce. The case is similar to that of a note being struck on a violin which is intermediate between the B and C of an organ. We never think of regarding the impression thus produced on the ear as being caused by a *mixture* of the vibrations appropriate to B with those appropriate to C, but we conclude the vibrations to be intermediate between the two. So, when in the spectrum the green and the blue appear to pass insensibly into each other, causing us to perceive what may be either a greenish blue or a bluish green, we are not to regard this confused impression as produced by an intermixture of true green rays with true blue rays, but as generated by waves whose length is intermediate between that of waves which produce a green and that of waves which produce a blue.*

In determining the character of vibrations, we in one respect judge more readily by the eye than by the ear. There is perhaps not one individual among ten thousand who could, when any particular note is struck alone, pronounce at once and correctly what note it is, and those who do possess this power arrive at their conclusion by reckoning from an artificial standard note fixed by long habit in their minds. On the other hand, there are comparatively few individuals who could not, when any pure colour of the spectrum is presented

* The analogy between light and sound in this particular is illustrated in a striking manner by an experiment communicated by M. Purkynie to the Bohemian Society of Sciences. Taking two hearing trumpets with long flexible tubes, and uniting them at the smaller extremity into a single tube, he introduced the latter into one ear, the other ear being stopped. One note was sounded at the further extremity of one of the trumpets, and a different note was simultaneously sounded at the further extremity of the other. The result was, that a note intermediate between the two sounded was heard as if in the interior of the head. When articulate sounds were similarly treated, the effect resembled that produced by pronouncing a diphthong.

alone to the eye, pronounce at once and correctly what colour it is. Hesitation is felt only as respects the intermediate tints, whose differences of vibration thus present in this particular a stronger analogy to those in musical notes; while the differences between distinct colours, such as between blue and green, bear in this respect a closer resemblance to the distinction which the ear observes between the tones of different instruments; for there is experienced as little difficulty in distinguishing by the ear between the tones of a flute and those of a violin when heard alone, as in discerning by the eye the green of the spectrum from the blue.

In another respect, however, the ear is a much more delicate test of differences of vibration than the eye. There is a large number of luminous vibrations whose differences the eye cannot detect, and which therefore convey to it one and the same impression of tint, as shown by the breadth of the coloured spaces in the pure spectrum. But there is no corresponding phenomenon in the case of sounds. Each note of the musical scale is formed by vibrations of a determinate rate. All departures from that rate, constituting degrees of flatness or sharpness, the ear can readily detect when they are presented to it in rapid succession, or enter into the composition of a musical chord. A cultivated ear, moreover, has no difficulty in ascertaining the elements which enter into the composition of any regular chord; whereas, it is rarely that the eye is able to determine the elements entering into the composition of a tint, formed by combining three or four pure colours. The range of vibrations appreciable by the ear also very greatly exceeds that of those appreciable by the eye. The extreme differences of vibration which affect the eye correspond to a single octave in the musical scale; whereas, the extreme differences which can be perceived by the ear embrace several octaves.

The circumstance that there are ethereal vibrations, whose degrees of rapidity are such as to produce a perception intermediate between two colours, suggests the probability that there may be vibrations of a certain degree of rapidity which produce the perception of mere brightness, or of pure white. The phenomenon already mentioned, that the reflex action of the optic nerve produces the same mental impression as would be derived from the action of white light on the retina, shows that the perception of whiteness is due to a certain condition of the nerve, which may be induced otherwise than by the outward impulse of ethereal waves; and it is therefore far from improbable that this same condition of the nerve may be excited, not only by the combined action of many waves of different lengths, but also by the simple action of waves of a certain determinate length. Indeed, Sir David Brewster avers that he has isolated white light, which is incapable of prismatic analysis. This view, moreover, would explain the remarkable fact that persons afflicted with colour-blindness have no difficulty in perceiving white, and that a similar condition of the retina may be temporarily induced even in a healthy eye. For if we gaze at the refracted spectrum obtained from a linear focus of white light, with one eye, holding up the eye-lid for some time, the retina will become insensible to the different colours in succession, and at the end of about half a minute the only perception that will remain will be that of mere brightness, or pure white. Thus the retina may be temporarily brought into such a state of insensibility to colour, as to be unable to discern the difference between a pure white image and one presenting all the colours of the rainbow. To a contrary action on the optic nerve is to be attributed the appearance of colours, produced in Mr. J. Smith's experiment of whirling white discs with patterns cut on them in front of a black

ground. That these colours are not real, but merely the result of the dazzling of the eye, has been shown by Mr. Rood, who, on examining the whirling discs through coloured glasses, ascertained that the effect is what would be produced by the transmission, not of coloured, but of white light. The speculations which Mr. Smith seemed disposed to found on his experiment have thus been somewhat *rudely* dispelled.

Whatever opinion may be formed on these two points, of there being waves which produce a perception of mere brightness, and of there being an impression of colour producible by successive impulses of pure white light, it is needful to guard the mind against the supposition that, in refracted spectra, where the colours appear blended at their boundaries, the effect is due to the circumstance of there being waves of the *same* length which produce *different* impressions of colour; for such an idea is altogether at variance with the undulatory theory, which recognises no other cause of difference of refrangibility and colour than difference of wave-length. Those blended impressions must therefore be attributed, not to intermingled waves, but to waves of intermediate lengths.

CHAPTER XII.

"What is hid bringeth He forth to light."—JOB xxviii. 11.

To return to the fixed lines of the spectrum: it has been shown that, in the spectra produced by different refracting media, the mutual distances of those lines vary exceedingly from what they are in the pure diffracted spectrum. This remark applies to the seven principal lines. But with respect to the whole set of lines which appear in the diffracted spectrum, refracting media affect them very variously, and that in opposite ways. For example, in prisms made of ordinary mercantile glass, whether flint or crown, these lines are, for the most part, wholly obliterated; and to obtain them the prism must be made of glass manufactured for the purpose. This obliterating effect of mercantile glass is due to its want of uniform density. It is, in fact, a mixture of glass of various degrees of density, for the most part disposed in layers, which are often distorted and intermingled, giving rise to the streaks discernible in all such glass when viewed in certain positions. To exhibit the fixed lines the prism must be made of glass perfectly uniform in density, which can be obtained only by a peculiar method of manufacture. All other media labouring under this defect of variation in density produce a similar effect in obliterating the fixed lines; because the spectra thus obtained are not simple, but composed of a multitude of small spectra overlapping one another, so that the resulting spectrum is a mixture of decomposed and recomposed light, in which rays of different degrees of refrangibility are brought to coincide in position. Hence

the blending of the different tints and the obliteration of the dark lines.

But with all prisms composed of media of uniform density the effect is the reverse, the fixed lines being increased in number beyond those developed in the diffracted spectrum. The additional lines thus exhibited are termed lines of absorption, because they are considered to be due to the absorptive power of the medium of which the prism is composed. That this view is correct is rendered highly probable by the remarkable action, upon the light transmitted through it, exerted by nitrous acid gas, which develops in abundance lines similar to those of the diffracted spectrum. The lines thus produced increase rapidly in number as the temperature of the gas is raised, becoming blended together, and forming black bands of various breadths, until, at a certain point of temperature, the whole of the light disappears and the gas becomes absolutely opaque. Vapour of iodine presents similar phenomena. It may hence be fairly concluded that the additional lines developed in various refracted spectra are due to a similar action of the substance of which the prism is formed.

This phenomenon may be explained, in accordance with the undulatory theory, by supposing more or less of the vibratory motion to be transferred from the particles of the ether to those of the substance composing the prism, and gaps to be thus formed in the continuity of the system of waves—the motion in certain of the primary lines of propagation in this manner becoming, to our visual perception, wholly obliterated.

These lines of absorption have recently acquired additional importance from their having been found available in chemical analysis. It has been mentioned, that in the spectrum produced by the electric light there are certain bright

lines. Now, it has been ascertained by Professors Bunsen and Kirchhoff, that each of the chemical elements, when introduced into the electric light, develops bright lines peculiar to itself. They have also found that the presence of one element does not prevent the development of the lines peculiar to another; so that, when several elements in combination are introduced into the light, the bright lines peculiar to them all are found in the spectrum. As a general rule, moreover, a combustible element will present the same characteristic lines with whatever substance it combines to form a salt; but in some instances the lines are modified by the nature of the combination.

These phenomena are rendered more striking by introducing the elements into the flame of hydrogen gas, which, being itself very feeble, renders the coloured lines more distinct. The following are some of the more remarkable of the lines thus developed:—Sodium gives a bright yellow line; lithium, a faint yellow, a bright red, and, at a high temperature, a clear blue line; potassium, two red and a violet; strontium, six red, an orange, and a blue; barium, twelve lines in the orange, yellow, and green spaces—two of the latter being the most conspicuous. Calcium gives a green line and an orange group; zinc and silicon, each two broad green bands. Mercury presents a peculiar spectrum, remarkable for a very distinct line at the extreme violet end; it also shows a bright blue line, and a group in the yellow. All the other metals, when in a state of combustion, exhibit similar characteristic bright lines or bands, but less conspicuous than those above enumerated.

Messrs. Bunsen and Kirchhoff have, by this species of analysis, discovered two new metals—the one of which they call cæsium, distinguished by two bright blue lines; the other rubidium, characterized by two lines in the extreme

red, two less conspicuous in the yellow, and two in the violet. A third new metal has been discovered by Mr. Crookes, which he names thallium, exhibiting only one bright green line.

Some of these spectra are nearly dark in every other region, except where the bright lines appear. This is particularly the case with sodium, lithium, and thallium. In other cases, considerable regions of the spectrum are moderately illuminated, besides the very bright lines or bands. For example, potassium, cæsium, and rubidium present a continuous brightness in the yellow and green—more partially in the blue.

In some instances, different metals give certain lines which appear exactly to coincide in position. For example, iron and magnesium each present a coincident green line; and iron and calcium each another coincident line, also in the green space, near Fraunhofer's line E.

A curious law has been determined by M. Kirchhoff, which connects the bright with the dark lines. He has ascertained that when, instead of the element being introduced into the flame, the light is transmitted through the element in a vaporous condition, there is a black line produced in place of the bright one. For example, when the metal sodium, or any of its salts, is introduced into the electric light, there is developed, in the region of the yellow, a very bright line; but if the light be transmitted through the vapour of sodium, this same line appears quite black. And so with the other elements.

The law may, in general terms, be stated thus: "Every combustible element, when in a state of vapour, absorbs most largely the same kind of light which it generates most largely when in a state of combustion."

There is another similar law regulating the brightness of

the beam—namely, that "the power of a combustible, when in a state of vapour, to absorb light passing through it is proportional to the brightness of the light which it generates when it is burnt." Or, in more general terms, "the power of a gas or vapour to arrest the undulatory motion of the ether is in exact proportion to its energy in propagating ethereal waves." Moreover, both of these powers bear a certain proportion to the size of the chemical atoms of the substance. For example, hydrogen gas, whose atom is the smallest known, generates, when burnt, a very feeble light; and it exerts a correspondingly weak power of absorption on light transmitted through it. But olefiant gas, whose atoms are complex and large, is powerful in propagating ethereal waves, and equally energetic in arresting them on their passage.

All these three laws receive a simple explanation from the undulatory theory. When the molecules of a body vibrate in such a manner as to produce a superabundance of waves of a certain definite length, then waves of that length, in passing through an assemblage of such molecules in a vaporous condition, will, more readily than any of the others, deliver over the whole of their motion to the ponderable atoms, and so appear to be arrested or absorbed. A large atom also must obviously, by its vibrations, create a greater disturbance of the ether than will a small one. It must generate vibrations of greater amplitude—consequently produce a light of more intense brilliancy. In like manner, when luminous waves pass through a vapour composed of large atoms, a greater number of them generally will be arrested, and forced to impart their motion to the molecules, than in the case of a vapour composed of small atoms.

The mass of the vapour employed also affects both the development of the bright lines and their absorption. The

greater the mass, the greater the brilliancy of the lines developed on the one hand, and the more perfect their absorption on the other. An increase in the mass of vapour thus sometimes develops lines that are invisible when the mass is small. It augments the brightness of all the lines, but of the weaker in a higher proportion than of the stronger; so that the former sometimes appear ultimately to rival the latter.

Similar effects attend a rise of temperature. Some of the lines become visible only when the combustion is carried on at a very intense heat; as, for example, the bright blue line in the lithium spectrum, and several of those presented by calcium. Increase of temperature tends to render the whole of the spectra more generally luminous.

On the other hand, the absorptive power of metallic vapours increases as the temperature diminishes, contrary to what is observed in nitrous acid gas. This seems to be owing to the greater density of the metallic vapour at the lower temperature.

Increase neither in the volume of the vapour nor in its temperature at all affects the *position* of the bright lines or those of absorption.

A somewhat anomalous effect of very high temperature has been observed by M. Fizeau, who found that, on burning sodium with an intense heat, the whole of the spectrum became luminous, and of its ordinary colours, except the sodium line, which appeared *black*. This phenomenon probably arises from the circumstance that the mass of the sodium becomes incandescent before combustion, and so produces the ordinary spectrum exhibited by other incandescent bodies, but that it becomes surrounded by a quantity of vapour containing sodium, which is sufficiently absorptive to obliterate the sodium line formed by that portion which is in actual

combustion. This explanation is confirmed by an experiment performed by Mr. Crookes, who found that when sodium is burned in a room, its atmosphere becomes so impregnated with the vapour of soda, that all flames lighted in the apartment acquire the characteristic yellow tint. But if, in front of any large flame giving out this tint, there be placed a small one containing a fragment of soda-salt, the latter will appear surrounded by a dark margin, caused by the rays of the larger flame becoming absorbed by the soda vapour arising from the smaller. So also, if sodium be vaporized in a sealed glass tube filled with hydrogen gas, the vapour of the sodium, which is quite invisible by ordinary light, appears like black smoke when viewed by the sodium light, owing to its high absorptive power over the sodium rays.

The sort of connection, which may be found to subsist between the atomic weights of the elements and the character of the ethereal vibration which they produce, is a subject of inquiry presenting a wide and almost untrodden field of research. It is easy to conceive how an atom of a definite weight should, when in a vaporous condition, always vibrate at one determinate rate; and the circumstance, that the elements generally retain their characteristic lines even after entering into union with others, seems to indicate that when such atoms combine, they do not pass into absolute contact, but each element remains free to vibrate independently at its own peculiar rate.

Little difficulty would be experienced in this investigation, did the atom of each element, when in a vaporous condition, appear to vibrate at one particular rate and no other, producing light of one colour only, as happens with sodium and thallium. The great puzzle is with those elements which generate several lines of different colours. Where the lines are of the same colour but separated by dark intervals, these

last may be presumed to arise from absorption, either by the prisms or by intervening vapours. But where the lines are diverse in colour the case is more perplexing. For all the atoms of an element must be presumed to be of the same size and weight. They ought, therefore, when in a vaporous condition, to vibrate in the same time, and produce the same colour. The only explanation which appears admissible in the present state of our knowledge is, that these various colours are due to the presence of minute quantities of other elements, some of them, perhaps, as yet unknown, which it has not been found possible, by any chemical means hitherto employed, to separate from those substances which exhibit these variously coloured lines.

The probability of this explanation is strengthened by the extreme minuteness of the quantity of any element which suffices to exhibit the distinctive lines—a circumstance warranting the inference that each individual atom of the element propagates by its vibration the characteristic wave. The discovery of the three new metals before mentioned also enhances the probability of the differently coloured lines being due to the admixture of different elements. This view is further confirmed by the coincidence of certain lines, to which reference has been already made. The coincidence of one of the lines in the iron spectrum with a calcium line, and of another with a magnesium line, would be most easily explained by supposing that, in the iron examined, there were minute quantities of calcium and magnesium which had not been found separable by chemical analysis, but whose presence was thus rendered sensible by these distinctive lines.

Some of the differently coloured lines, however, may be explained on a principle not inconsistent with the foregoing. In every process of combustion there is a chemical combination formed between the combustible and some supporter of

combustion. In some instances there is simultaneously in progress a disengagement of the combustible, or supporter, from some previously subsisting combination. Now, each of the elements present will vibrate in its own time, and propagate its own ethereal wave; and although that propagated by the combustible may be so conspicuous as to throw the others into the shade, yet these different systems of waves may, at certain regular intervals, so interfere as to concur in producing waves of definite colour, intervening between the wave produced by the combustible and that propagated by the supporter; and these intervening waves may produce lines of such brightness as to become conspicuous to the eye. This explanation, however, still involves the idea that the diversity of colour is due to a diversity in the elemental atoms producing the lines.

There is a source of fallacy against which it is needful in these investigations to be on our guard. It frequently happens that, while being burned, portions of the combustible element become more or less incandescent before suffering actual combustion, so that the flames in which this happens produce compound spectra, of which one part is due to the incandescence and is diffusely luminous, while the other is due to the combustion of the elemental vapour and exhibits the distinctive lines. This effect is exemplified in the generality of carbonaceous flames, which all owe their brilliancy to incandescent carbon, and not to the combustion of carbon vapour. To exhibit the characteristic flame of the latter, it is necessary to burn carbonic oxide gas, which disengages no free carbon during its combustion. The distinctive colour of the flame of carbon vapour is then seen to be blue.

It is probably to the admixture of incandescent light with that derived from combustion, that we are to attribute the diffuse brightness observable in the spectra of potassium,

cœsium, rubidium, and others similar. To eliminate this source of error the combustion should be conducted at as low a temperature as possible, and, when practicable, the combustible should be thrown into the vaporous condition before being burned.

In pursuing this investigation there may probably have to be taken into account, besides the atomic weight, some specific force exerted by each species of elemental atom upon the substance of the ether. Should it be ultimately found that there is only one definite set of waves of the same tint propagated by the atoms of each element, then the rate of vibration due to those waves would be the measure of the specific force which the elemental atom exerts in imparting motion to the particles of the ether. That some such force exists is rendered probable by the circumstance of there being no apparent proportion, between the atomic weights of the elements and the lengths of the ethereal waves which they propagate.

CHAPTER XIII.

"Thou hast prepared the light and the sun."—Ps. lxxiv. 16.

It has been mentioned that the bright lines, developed when an elemental vapour is burning, are converted into dark lines on light being transmitted through those vapours in their simple state. Some of these bright or dark lines are found exactly to coincide in position with certain of the dark lines in the solar spectrum. This is particularly the case with the distinctive line of sodium, which precisely coincides in position with the fixed line D of Fraunhofer in the yellow space. Similar coincidences of position with well defined lines in the solar spectrum, have been observed in the lines developed by iron, calcium, magnesium, chromium, barium, nickel, copper, and zinc.

These remarkable coincidences have led M. Kirchhoff to infer that the above elements exist, in a vaporous condition, in the atmosphere surrounding the luminous surface of the sun, and producing the corona of glory during total eclipses, and that the dark lines of the solar spectrum are caused by the sunbeams passing through such vapours. This inference may be just, but it is, in the present state of our knowledge, rather premature. It not unfrequently happens that the light of the aurora borealis assumes various vivid hues, such as crimson, green, blue, violet, &c. Until these coloured lights be analyzed by the spectrum, it will be prudent to refrain from coming to a conclusion on this point. If these coloured lights be found to yield spectra, corresponding with those obtained by the transmission of light through the vapours of certain combustible elements, one of two inferences might be

drawn—either that the coloured lights indicate the presence of those elements in a vaporous condition in the higher regions of the earth's atmosphere, or that electricity, in passing through strata of air of different densities, and impregnated in various degrees with aqueous vapour or minute crystals of ice, is capable of developing coloured lights which simulate those obtained from elemental vapours.

Of these conclusions the former would be the more legitimate. Indeed, it is demonstrable that the earth's atmosphere does exert a very strong absorptive power on the direct solar rays. Nearly a half of the whole amount of rays, arriving at the outer surface of the terrestrial atmosphere, are absorbed in their passage through that medium, being converted into heat. It is not surprising, therefore, to find the dark lines in the solar spectrum so very numerous as they are. The wonder would be were it otherwise. That the terrestrial atmosphere is concerned in the production of those lines is further evidenced by the circumstance of their increasing very considerably in number, when the sun is near the horizon. Not only so, but in this position of the sun the principal lines become sensibly approximated by increasing in breadth. This increase takes place only towards the more refrangible side of each line, so that the absorptive power of the atmosphere, arising from the increase of its mass, acts more powerfully on the more refrangible rays. Hence the ruddiness which the sunbeams acquire towards the horizon.

That the vapours of the substances, which originate lines corresponding to those of the solar spectrum, should be found in the earth's atmosphere, would not be surprising. It has been ascertained by M. Kirchhoff himself, that these elements are almost universally diffused in the earth's waters and superficial soil, and may, therefore, exist in a vaporous

condition, in very minute quantities, diffused throughout the atmosphere. He expressly admits, indeed, the existence of sodium in a vaporous condition in common air—a fact not at all surprising when it is remembered how widely soda salts are diffused through the ocean. Some of these elements, more-over, have an odour sensible even to the human nostril, while others may emit odours perceptible to the keener sense of the dog. Such odours give evidence that the substance is vaporized, and becomes blended with the air at natural temperatures.

There is one remarkable fact, which throws the preponderance of probability in favour of the view, that the lines of the solar spectrum are due to the action rather of the terrestrial than of the solar atmosphere. The light derived from the edge of the sun's disc does not exhibit the lines in greater quantity, or with deeper intensity, than does the light derived from the centre; whereas, in the case of the earth's atmosphere, their increase both in number and intensity towards the horizon is quite sensible. M. Kirchhoff endeavours to meet this objection, by supposing the increase of mass to be proportionally less in the case of the solar than in that of the terrestrial atmosphere, so that the absorptive power at the edge may differ very little from what it is at the centre of the sun. But this hypothesis has to encounter a most formidable difficulty. When the sun is totally eclipsed, there are certain luminous prominences seen projecting beyond the dark edge, and having a rose-red colour. This fact shows that the absorptive power of the solar atmosphere is very greatly augmented towards the edge by increase of mass, and proportionally much more than is that of the earth's atmosphere, which only slightly reddens the sun's rays when he is near the horizon. It would be exceedingly interesting to have the red light of these prominences analyzed by the prism.

The increase of absorptive power towards the edge of the sun is further proved by the circumstance, that in photographic images of his disc, the brightness is greatest at the centre, and fades off gradually towards the edge.

Another point ought not to be overlooked in this inquiry, namely, the extreme tenuity of the sun's atmosphere in the region beyond his luminous surface, as compared with that of the earth. This is proved by the fact, that while it exerts a considerable amount both of reflective and absorptive power, the refractive power of the solar atmosphere is scarcely appreciable. This indicates that its tenuity resembles that of the tail of a comet, or of the earth's atmosphere at the height of forty or fifty miles, where its refractive power ceases.

The facts above enumerated all tend to render it more probable that the absorptive power, which causes the dark lines of the spectrum, resides in the earth's atmosphere rather than in that of the sun.

On the other hand, from some observations made on the spectra produced by the fixed stars, it appears that certain of the dark lines are absent from some of these spectra, and present in others—a circumstance tending to show the lines in these spectra to be due to some other cause than the absorptive action of the terrestrial atmosphere. These observations, however, are as yet too few and uncertain to be regarded with much confidence. The extreme feebleness of the light of the fixed stars must render any observations of this kind very difficult, and it is most desirable that they should be repeated and multiplied with great care. Meanwhile it must be regarded as an undecided question, whether the lines are due to the absorptive action of the solar or of the terrestrial atmosphere, or partly to that of both.

M. Kirchhoff entertains an idea that the sun consists of a

solid, or rather a liquid incandescent mass, surrounded by an atmosphere containing those metallic vapours, which produce some of the more remarkable of the fixed lines. But this notion is discountenanced by the phenomena of the solar spots, as observed by Wilson, Herschell, Arago and others, tending to show the spots to be depressions on the solar disc, and not dark clouds floating over an incandescent surface. These observations indicate that the luminous region is gaseous; that immediately under it lies a region generally occupied by dense vapours, which screen the more compact surface of the sun from the glare of the luminous envelope. These vapours form the penumbra surrounding the spots, while the dark portion in the middle of each spot is the compact surface of the sun, which appears black by contrast with the luminous region. The curious discovery of Mr. Nasmyth, that the luminous envelope consists of willow-leaf shaped masses in a state of perpetual motion, and sometimes seen travelling across the spots, tends to establish the same conclusions. This view of the constitution of the sun is further corroborated by the rose-coloured prominences seen in total eclipses. These are evidently detached masses of the luminous material rising above the general surface, and that in such fantastic shapes as to prove that they can be neither solid nor liquid, but must be in a vaporous or gaseous condition. The notion of M. Kirchhoff, that the mass of the sun is an incandescent liquid, is further discountenanced by the very small amount of the observed difference between the two diameters of the illuminated disc ($0''\cdot1$), as determined by Professor Airy; whereas, were the luminous surface that of a continuous liquid incandescent mass, the form would be that of a spheroid of revolution, whose two diameters would be considerably more diverse. Of course, if the luminous surface be merely that of a

gaseous envelope, the solid mass of the sun may possess a far greater amount of oblateness in its figure.

The circumstance that the sun's light is wholly unpolarized, has likewise been shown by M. Arago to militate against the supposition of its proceeding from pure incandescence. The great *intrinsic* brightness of solar light is also very adverse to this idea. The most brilliant incandescence which we can obtain is that of the electric and lime-ball lights; but these, when viewed so as to present to the eye the same angular diameter as the sun (32′·33″·6), are inferior to him in *intrinsic* brightness, by at least threefold; while solar light loses about one half of its primary intensity in passing through the earth's atmosphere—a circumstance which doubles the above proportion. Such an intensity of illuminating effect can, so far as we know, be obtained only by very numerous small centres of illumination transparent to each other's light, placed behind one another, and forming a stratum of great thickness—as when a multitude of gas flames (say four or five hundred) are placed in a row and viewed lengthwise, so that their united light shall reach the eye along one and the same principal line of propagation. Lastly, the very low specific gravity of the solar orb, little exceeding that of water, almost compels us to suppose the luminous region to be gaseous. For looking to the enormity of his mass, and to the increase of density arising from compression, the superficial parts of his substance must be very much lighter than water, in order that his mean density should so little exceed the aqueous standard. If his luminous surface be merely gaseous, and separated by a very thick stratum of vaporous material from his compact surface, then we are at liberty to suppose the latter to consist of land and water like the surface of our globe. But we know of no substance so much lighter than water which could constitute

the luminous surface in a state of high incandescence under the solid or liquid form.

This part of M. Kirchhoff's hypothesis, however, has no necessary connection with the formation of the fixed lines; for, even were it capable of proof that these lines are due to the absorptive action of the atmosphere surrounding the sun's luminous surface, it would not thence follow that the light must emanate from a solid or liquid incandescent mass. The luminous envelope might still be gaseous, and its light might be derived from any conceivable source whatever. In fact, we have absolutely no proof that solar light may not be primarily deficient in the sodium and other lines. The idea of its being an incandescent light—which, save for the intervention of absorptive vapours, would present a continuous, uninterrupted spectrum—is, after all, a mere assumption, made in order to raise a probability that these absorptive vapours exist in the exterior atmosphere of the sun. The same remark applies to the case of the fixed stars.

There is an experiment which it would be difficult to make, but which, could it be accomplished with certainty, would greatly help to decide this question. If, when any large spot appears on the sun, the whole of the surrounding luminous surface could be excluded from the field of view, and the feeble light of the penumbra, and still feebler light of the centre of the spot, be subjected to separate examination, it might then be ascertained by the polariscope whether it be direct or reflected. If the light of the spot and its penumbra be polarized, the probability would be that it is reflected, and this result would go far to prove that the direct solar light proceeds from an outer gaseous envelope. It would also be very important to have observations on the solar spectrum made at great heights, to determine the effect

of the diminished mass of air in reducing the number and lowering the intensity of the fixed lines.

Besides the light of the Aurora Borealis, of the red solar prominences, and of the fixed stars, there is another class of lights which it would be interesting to subject systematically to prismatic analysis, namely, those exhibited by fluorescent and phosphorescent bodies, especially the latter. The light emitted by organic beings such as the fire-flies, and those minute organisms which produce the phosphorescence of the ocean, it would be highly important to examine in this manner.

In prosecuting further researches in spectrum analysis, it would be desirable to substitute, for the spectrum obtained by means of glass prisms, the pure diffracted spectrum produced by a system of fine equi-distant lines. These can now be drawn by M. Nobert so very fine, that there may be 150,000 to the inch—thus admitting of considerable magnifying power being applied to the spectrum. By this substitution the dislocation of the lines produced by the prisms, and the absorption of some lines by the action of the glass, would be avoided. There is reason to suspect that many of the lines observed by M. Kirchhoff, in addition to those found by Fraunhofer in the diffracted spectrum, are owing solely to the absorptive power of the four glass prisms, which are employed in the apparatus used by the former observer. There is also another source of fallacy arising out of the use of prisms. The light being introduced through a fine slit, there must be produced at both edges of the slit diffracted fringes. These diffracted waves may, to a certain extent, interfere with the refracted waves, sometimes exalting, sometimes diminishing their brightness; so that both bright and dark lines may be developed from this cause.

It would be interesting to examine the colourless spectrum

of solar light which may be obtained from prisms of pure glass, perfectly achromatized, to ascertain whether any of the lines can be detected in it, and then to apply the same system to the spectra of the chemical elements. This method might eliminate certain causes of error.

The consideration of the absorptive action of different media naturally brings us to the third method of analyzing white light; namely, by passing it through media, which have the power of absorbing all the rays but those of one colour. It is seldom that this effect can be perfectly produced by a single medium; but it can always be done by the combination of two or more. In this manner each of the pure colours of the spectrum can be isolated, and transmitted to the eye free from admixture. The light is then found to be incapable of further analysis, either by refraction through a prism, or by the diffraction resulting from a system of fine equidistant lines. When the perfect purity of the light has been thus tested, the *mean* wave-length, corresponding to the tint, may be determined with considerable accuracy, by letting the light fall on two plates of parallel glass, inclined to each other at a very small determinate angle, by which method the system of waves is rendered palpable to the eye. But it must be borne in mind, that in all coloured light, even of the most perfect purity, there are embraced waves of different lengths, lying between two definite limits; so that it is only the *mean* of the several wave-lengths, that can be determined in this manner.

The action here is all referable to the transference of motion from the ether to the ponderable medium, whose molecules acquire nearly all that motion, which becomes imperceptible to the visual organ. A question thus arises whether the coloured light obtained is any portion of the original light, left unaltered, by reason of certain definite

waves failing to transfer their motion to the molecules of the medium; or whether the coloured light should not be regarded as light, which has had its wave-lengths modified and determined by the reaction of the molecules on the ether.

The law of M. Kirchhoff, before stated, seems at first sight to favour the idea, that the light transmitted through coloured media is itself part of the incident light, deprived of a determinate portion of its waves. But the absorption by vapours of certain definite waves, and these the same that are generated most abundantly by those vapours when in a state of combustion, is a phenomenon so different from that of the absorption of light by solid or liquid coloured media, that it would be imprudent to reason by analogy from the one to the other. While the law of M. Kirchhoff can be relied on as a chemical test, indicating the presence of certain elements, on the light transmitted through coloured solids or liquids, as a similar indication, no reliance can be placed. For example, the presence of copper, either pure, or in any of its combinations, can always be detected by the green tinge which it imparts to flame. But a salt of copper, in solution, may transmit either a green light, as in verdegris—or a blue, as in the nitrate—or a violet, as in the ammoniuret of copper. So also it was for long supposed that the colours of emerald, aquamarine, amethyst, topaz, &c., were due to metallic oxides, but it has recently been ascertained that they are due to the presence of certain combinations of carbon and hydrogen mixed with the minerals. It is, therefore, evident that these transmitted tints are owing to a different cause, from the definite absorptive action of the chemical elements in a vaporous condition, so that the question respecting their nature may be regarded as still undecided.

A curious instance of the gradual development of the

absorptive property is presented by the solution of the bark of the horse-chesnut. If a drop of the tincture of this bark be let fall into half a tumbler of rain water, it will presently reflect the beautiful blue tint due to its fluorescence. But in some hours it gradually assumes a pale buff colour by transmitted light; still, however, showing the blue reflection. On the second day, the buff tint predominates, while the blue disappears; and on the third day, the water acquires the colour of brown sherry. Here no new element is introduced; the change can be traced only to an alteration in the arrangement of the chemical atoms.

In the above case, the fluorescent property is first gradually overpowered, and then supplanted by the absorptive. In some media, however, these two properties continue to subsist together, giving rise to what is termed *dichroism*, or double colouration. For example, a solution of chlorophyll, or leaf-green, gives a green reflected light by virtue of its fluorescence, and a red transmitted light by means of its absorption. Solutions of litmus give a blue reflected, and a red transmitted tint. In these instances, the effect appears to be due to the presence of more than one sort of chemical atom.

Some absorptive media affect the mutual distances of the fixed lines of the spectrum, more or less according to their density. Thus hyponitric acid gas diminishes the distance between the fixed lines, as the density of the gas increases. Tincture of chlorophyll exerts a similar action, increasing with the strength of the tincture. In both instances, this diminution of distance is owing to an increase in the breadth of the lines, on their more refrangible side only. The effect is similar to that already mentioned, as taking place in the earth's atmosphere, near the horizon.

CHAPTER XIV.

"He scattereth his bright cloud, and it is turned round about by his counsels."
—Job xxxviii. 11, 12.

The fourth method, by which white light may be analyzed, and its component colours presented to the eye, is by *polarization.* When light has been polarized in one plane, either by reflection, or by transmission through a doubly refracting medium, or a bundle of thin plates, it is needful to subject it to a second reflection, or to transmission through a second doubly refracting medium, in order to show that it has been polarized. But if, between the first and second polarizing surface or medium, there be interposed a doubly refracting medium of any kind, this last has the power of either wholly or partially depolarizing the light, or at least of altering its plane of polarization; and owing to the unequal refrangibility of the waves of different lengths, this alteration affects the waves unequally; they become more or less separated, and thus affect the eye with the perception of colour. In this manner may be produced a series of phenomena of the most marvellous beauty, and at the same time of the highest utility; for by the appearance and arrangement of the colours thus developed, we are able not only to distinguish one substance from another, but also in some instances, to exhibit to the eye the intimate structure of bodies, and the arrangement of their molecules.

To enter into any description of these beautiful phenomena would involve too much detail; and it is unnecessary, seeing the whole depend on one and the same principle. There is first the polarization of the light, which, according

to the undulating theory, consists in reducing to one plane the vibrations of all the individual particles, in the several axes of undulation. It is easy to see, that a vibrating particle, which is free to vibrate in any direction, or in any plane whatever, may, by encountering an obstacle to its free vibration in any one direction or plane, be made to vibrate in another direction or plane, without losing any of its vibratory force. This point can be easily demonstrated, by means of the suspended magnetic needles already described. But when vibrations, which are all performed in one plane, enter a medium, in which the freedom of motion is less in that particular plane, than in some other, their plane of vibration will be correspondingly altered, and the amount of this alteration will have a certain dependence on the length of the waves; for on entering any doubly refracting medium, in which there are layers of different degrees of density sym metrically arranged, the waves of different lengths pursue different paths, for the reason already explained, and consequently are turned from their plane of polarization in different degrees.

One of the most striking phenomena disclosed to us by means of polarizing and depolarizing media, is the condition of polarization of the clear blue sky during the day. Regarding the sky as a reflective polarizing surface, and using an analyzing eye-piece of tourmaline or calcareous spar, by interposing a depolarizing crystal, such as topaz, it will be seen that the sky is divided into two equal portions by a line passing through the centre of the sun, and that the light coming from these two portions, is polarized in opposite planes. The light reflected by the eastern half is polarized in one plane, and that reflected by the western half in the opposite plane. The line of separation is best distinguished by the observer turning his back to the sun, and examining

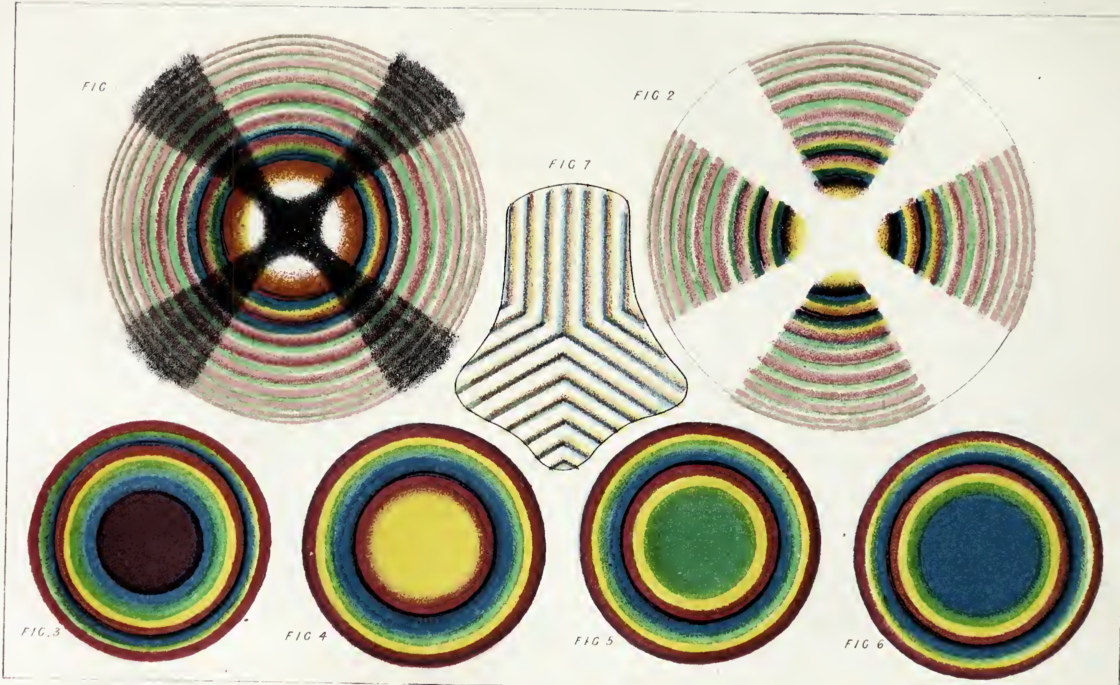


PLATE I.

POLARIZATION OF LIGHT.

the region of the sky immediately opposite to the luminary. It will then be seen, that the polarization passes quite suddenly from the one plane to the other, aud that the line of separation, if prolonged, will pass through the centre of the sun. If the region of the sky near the sun be examined, it will be found that the quantity of direct light is so great, as to destroy the impression produced by the reflected and polarized light, so that the coloured rings are obliterated. The interception of clouds also obliterates these rings; because the light becomes wholly depolarized by transmission through the cloud; for light is polarized by reflection in a plane opposite to that in which it is polarized by transmission.

Besides the common or rectilinear polarization, there are other two kinds to which light may be subjected—the circular and the elliptical. The circular is produced by transmitting the polarized light through quartz, oil of turpentine, and a few other media, the elliptical by reflection from metals. In the circular, the plane of polarization is made to rotate in a circle, by rotating the depolarizing medium. In the elliptical, the plane of polarization is made by the rotation of the metal to describe an ellipse. According to the undulatory theory, it is supposed that, while in plane polarization the individual vibrations of the ethereal particles are performed in one plane, and in a straight line, they are in circular polarization circular, and in elliptical polarization elliptical; the orbits being brought into these forms by the peculiar manner, in which the ponderable molecules of the medium exert their force on the vibrating ethereal particles.

A better idea of the beautiful phenomena, produced by transmitting polarized light through depolarizing media, than could possibly be conveyed by mere words, may be obtained

by a simple inspection of the three plates at the end of this chapter, with the explanations prefixed to them.

The last method of separating white light into its coloured elements, is by means of closely approximated polished surfaces, giving rise to the phenomena known as the colours of thick and thin plates. Of this nature are the colours observed in soap bubles, films of mica, feathers, &c. The phenomena belonging to this class are often of exceeding beauty, as exemplified in the gorgeous plumage of the peacock, the brilliant hues of the humming bird, and the playful tints of the diamond beetle, the chameleon, the iguana, and the dolphin. These colours are all referable to one and the same cause; namely, the interference of the waves coming from one surface, with those coming from another near it; and it is, therefore, unnecessary to enter into details. The tints may be considered as purely adventitious, and as existing, not in the object, but in the eye alone, depending for their development on the manner in which they are observed. These colours are best exhibited by pressing a lens of long focus firmly against a flat plate of glass. There will then be seen a black spot in the centre, surrounded by a ring of white. Beyond this latter is a series of coloured rings, in which the tints follow a determinate order, the transmitted tints being complimentary to the reflected. This phenomenon is familiarly known as Newton's rings—Sir Isaac having classified the tints, and measured the thickness of the interval, where each is developed. They are seen in greatest perfection, when the lens and the plate ere so adjusted, that the air can be exhausted from between them.

Explanation of Plates I, J, *and* K, *illustrative of the Polarization of Light.*

PLATE I.

Fig. 1, Shows the appearance presented by calcareous spar cut perpendicularly to its single axis of double refraction, when viewed by polarized light.

Fig. 2, Represents the opposite phase.

Figs. 3, 4, 5, 6, Show four phases of quartz, a crystal possessing the property of rotatory polarization. Quartz is of two kinds,—the one, called right-handed, shows the central colours in the order presented in the plate, when the crystal is turned towards the right hand. The other, termed left-handed, shows the colours in the same order when the crystal is turned to the left hand.

Amethyst is composed of alternate layers of right and left handed quartz, arranged as shown in fig. 7, which represents a section of this mineral, under a magnifying power of about 80 diameters.

PLATE J.

Fig. 1, Shows the system of colours presented by a crystal of nitre, when cut perpendicularly to a line intermediate between its two axes of double refraction.

Fig. 2, Represents the opposite phase.

The other figures show sundry microscopic crystals under polarized light.

Fig. 3, Is the hyposulphite of soda. These crystals depolarize the *whole* light, and so appear white on a black ground.

Fig. 4, Is iodide of quinine.

Fig. 5, Lithic acid.

Fig. 6, Tartaric acid.

Fig. 7, Gallic acid.

Fig. 8, Nitrate of silver.

PLATE K.

Fig. 1, Shows the appearance presented by topaz, when cut in the same manner as the nitre in the preceding plate.

Fig. 2, Is the opposite phase. The other figures are microscopic.

Fig. 3, Shows the cells of the sugar-cane with crystals of sugar.

Fig. 4, Borax.

Fig. 5, Oxalate of ammonia.

Fig. 6, Chlorate of potash.

Fig. 7, Starch granules of tous le mois laid on selenite.

CHAPTER XV.

"Written with the finger of God."—EXOD. xxxi. 18.

THERE is one more class of phenomena of a totally different kind, which it is needful to notice, in order to show its bearing on the undulatory theory—namely, the power possessed by light, in common with several other causes, to produce on the surfaces of bodies certain molecular changes, which have the effect of altering their relations to other bodies. This property is exhibited in the various species of photography. It has already been pointed out, in reference to absorption, that in many cases a large portion of the motive energy, possessed by the ethereal particles, is by them transferred to the ponderable molecules of the bodies, with which they are immediately and momentarily associated. Now, the motion, thus acquired by the chemical atoms composing any substance, may be such as to give rise to some new arrangement of these among themselves, or, at least, so to modify them as to impart to them a predisposition to enter into new relations or combinations. This effect is most likely to be developed where the atoms are complex, and where the chemical affinity by which they are held together is weak. The transfer of motive energy from the ether to the chemical atoms, then, affords a satisfactory explanation of all the ordinary cases of photography. It is worthy of remark that this peculiar property of light is in general greatest in those waves that have the most rapid individual vibrations, and possess the greatest amount of inherent motive energy—namely, those in the violet portion of the spectrum, and even in the region beyond it, where the vibrations are so rapid as to produce no appreciable effect

PLATE J.

FIG 1

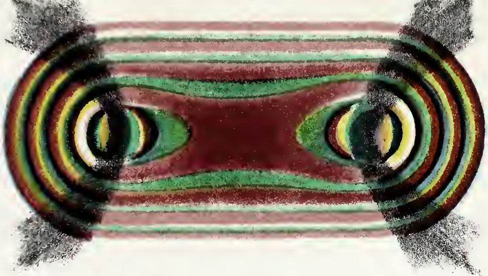


FIG 2

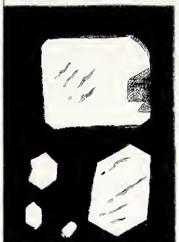


FIG 3

FIG 4

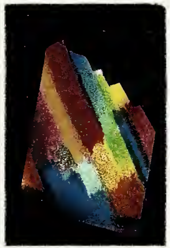


FIG 5

FIG 6

FIG 7

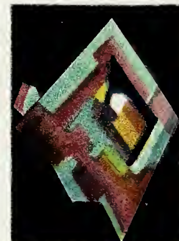


FIG 8

POLARIZATION OF LIGHT.

on the retina. It is a mistake, however, to suppose that this property is confined to those regions, or that it is possessed by rays altogether distinct in kind from the luminous rays. For all the luminous rays, of whatever colour, are capable of producing these peculiar molecular modifications; but the results of their action differ greatly with the nature of the substance composing the sensitive surface, and also with the length of time during which the action is continued.

From the circumstance of photography having assumed a place among the fine arts, it is apt to be regarded as an artificial process of man's invention. But in the development of natural colours, several instances of very marked photographic action occur. One of the most striking of these is presented by the beautiful bell-shaped flower of the *Cobœa Scandens.* On the first day of its full development, the bell is of a pale yellowish green tint; but it gradually assumes a purple hue, which, on the third day, acquires great depth and beauty, strongly resembling the tint which the chloride of silver gains by exposure to light. That the effect is photographic is proved by the circumstance that the flower, if kept in the dark, retains its primitive pale greenish tint.

In the production of any photographic impression, indeed, the mere human agency performs but a very subordinate part; and of all delineations thus obtained it may be truly affirmed, that they are "written with the finger of God."

Dr. Gladstone has shown that fluorescent bodies possess the curious property of depriving white light of a large proportion of its photographic power. Drawings delineated on white paper with the disulphide of quinine, which are quite invisible, produce photographic impressions when the image of the paper is taken in the camera. This property is reconcileable with either of the views previously indicated, with respect to the nature of fluorescence.

There are other phenomena, however, analogous to those of photography, which at first sight appear of a more puzzling kind, namely, those recently discovered by M. Niepce, and those previously brought to light by M. Moser, in both of which, judging from mere appearances, one might be led to the conclusion that light passes into a *latent* condition within the pores of bodies, and is thence slowly given out again.

M. Niepce observed, that if white paper having a design upon it, such as a copper-plate engraving or a printed page, be exposed for a considerable time to bright sunshine, and then immediately applied to a sheet of sensitive paper, with which it is allowed to remain in contact for twenty-four hours in a dark room, the white of the sunned paper will leave an impression on the sensitive paper, while the dark portions will not, so that a negative impression is obtained. The same result follows from exposing black and white marble, black and white feathers, &c.; and even some few colours give a feeble impression. But the most striking experiment is the following. If a tin tube, closed at one end, be completely lined with white paper, and its interior be exposed for an hour or so to bright sunshine; then if the tube be placed, with its open end downwards, on a piece of photographic paper, and be allowed to remain thus in a dark room for twenty-four hours, an impression of the mouth of the tube will be made on the paper. If a design on very fine tissue paper be interposed between the tube and the photographic paper, the image will be impressed on the latter. What is still more remarkable, if, after exposure to the sun, the tube be hermetically sealed, so as entirely to exclude the external air, and kept in this state for a long period of time, and if it be then opened in a dark room, and applied as before to the photographic paper, an impression will be obtained at the end of twenty-four hours.

Now, that the impression in this case is not due to light retained in a latent state in the pores of the paper, or other substance exposed to sunshine, and then slowly given out again, is made evident by a single fact. In all true photographic impressions, the interposition of glass forms no obstacle to the photographic action. On the contrary, it is found advantageous to place a glass plate in front of the sensitive paper in the camera obscura. Varnishes, transparent wax, &c., in like manner offer no hindrance; and it is well known that waxing the negatives is advantageous in obtaining positive impressions. In the case of the images procured by M. Niepce, it is quite otherwise. The interposition of even the thinnest glass, or of a film of mica, or of varnish, or wax, totally prevents the action; but the interposition of gelatine, collodion, skin, or tissue paper, does not. The interposed substance must, in order to interrupt the action, be a non-conductor of electricity and moisture; and it will have this effect however transparent to light it may be. But if the interposed film be a conductor of electricity and moisture, it will not interrupt the action. It is thus rendered evident that the production of the image is due, not to photographic, but to electro-chemical action; and the previous exposure of the white surface to sunshine merely induces the condition necessary to the development of the electro-chemical agency by which the image is really produced.

The case of the tube is the most instructive. From its being requisite to hermetically seal the tube after exposure to sunshine, in order to preserve for an indefinite time the property of producing the image, it is obvious that the column of enclosed air is an important element in the operation. The white paper lining, stimulated by the sunbeams, must alter, in some manner, the constitution of the air which comes into contact with it. Judging from the

result, it appears not improbable that this alteration may consist in the conversion of part of the oxygen of the confined air into ozone, and that it is this ozone which acts chemically on the sensitive paper. It is surely far more likely that what is thus bottled up in the tube for an indefinite period is air ozonized, or otherwise modified, than that it should be the concentrated essence of sunbeams.

The same explanation will apply to the other cases. The white surfaces, whether of paper, marble, or feathers, may, under the stimulus of the sunshine, convert that portion of the oxygen of the air in immediate contact with them into ozone, or may otherwise modify the adhering film of air, so as to enable it to act chemically on the sensitive paper. But where the surfaces which have been exposed to sunshine are applied directly to the sensitive paper, the action may be due to another cause. According to the views of Baron Wredé, the white surfaces are by the sunbeams stimulated into a condition of molecular vibration, which reacts upon the ether, and causes the production of fresh luminous vibrations. Now, this vibratory condition may continue for a time, after the exposure to sunshine, sufficiently long to set up a corresponding vibratory condition in the surface of the sensitive paper, and thus to commence a chemical action, which, once begun, has a tendency to continue. The circumstance, however, that the action takes place when a thin film of air is interposed between the two surfaces, rather favours the former hypothesis.

But whatever may be the true explanation of the development of the chemical agency by which the image is produced, it is manifest that light is not the direct and immediate agent in generating the image; consequently these curious phenomena cannot in any manner affect the evidences in favour of the undulatory theory.

CHAPTER XVI.

"He discovereth deep things out of darkness."—JOB xii. 22.

THERE remain to be considered, in their bearing on the undulatory theory of light, the remarkable discoveries of M. Moser, in regard to the production of images on polished surfaces in the dark, closely resembling those produced by the direct action of light. The experiments of M. Moser led him to the conclusion, that all smooth polished surfaces whatever exhibit, in proportion to their smoothness and the perfection of their polish, a tendency to receive from objects placed in contact with them, or very near them, latent images, capable of being developed by subsequently condensing on these surfaces vapours of various kinds,—such as those of water, mercury, iodine, or the like. The impressions are rendered visible, by the manner, in which the vapour is condensed on the portions of the surface which have been thus impressed, being different from that in which it is condensed on the other portions.

These images greatly resemble those produced by the action of light on surfaces of iodized silver in the process of Daguèrre,—a resemblance which betrayed M. Moser into the singular conclusion, that the impressions he obtained were due to the action of latent light, or invisible rays, similar to the invisible photographic rays of the spectrum, and that these invisible rays are continually issuing from all bodies whatever—this latent light being analogous to latent heat.

Now, that this is not the true explanation of these curious phenomena will become evident from the following considerations:—1st, The images of Moser are produced equally

well, whether we operate in the light or in the dark. 2d, The invisible rays of the spectrum are capable of acting at a distance; they can penetrate transparent plates of glass or mica, and they can be concentrated into a focus by a lens, or by a metallic reflector. But the supposed invisible rays of Moser differ in all these respects. The distance at which they can operate is very minute; they cannot penetrate the thinnest glass or the thinnest films of mica, and they cannot be concentrated into a focus by a lens of any sort, or by a reflector. In all these respects they differ also from the invisible rays of heat, which are, like the invisible photographic rays, capable of all these affections. It is, therefore, evident that some other cause, than that of a radiation resembling rays of light or heat, must be sought for to explain the images of Moser.

It has, accordingly, been shown very clearly by M. Waidelé, that gases or vapours are the real agents in the production of all these images. He demonstrates that the surfaces of all bodies, and all fine powders, have a tendency, more or less, to absorb gas or vapour, and to hold it adhering to them in a highly compressed or condensed state; but that of this layer of gas or vapour they may be deprived by artificial means,—as by heat, or by the near approach of a surface, or powder, whose power of absorption is for the moment greater. But if a perfectly polished surface be carefully deprived of all adhering gas or vapour, by heat, or friction with newly prepared charcoal, or freshly calcined tripoli; and if an object, such as an engraved seal or die, be in like manner deprived of all adhering gas or vapour, the latter will not impress any image on the former, by contact or approximation. Whereas if either the plate or the die be previously charged with gas or vapour, while the other is either left pure, or is charged with a different gas or vapour, an image

will be produced. Mere rubbing with the finger is sufficient to charge the surface with volatile matter; and exposure to the atmosphere, particularly when moist, for any length of time, has the same effect. The thinnest film of grease, or, indeed, of any matter whatever capable of being volatilized, adhering to one of the surfaces employed, while the other is pure, will likewise produce an image; and hence it is, that engravings on paper, or printed pages, when allowed to lie in contact with a clean surface of polished metal, or of glass, leave a latent impression, which may be rendered visible by the condensation of aqueous, mercurial, or iodine vapours.

The best method of illustrating this class of phenomena is to make use of a vapour like that of iodine, whose effects are at once apparent. If an embossed card be charged with the vapour of iodine, and laid nearly in contact with a very clean well polished plate of silver, from which all adhering gas or moisture has been removed, the design on the card will be visibly impressed on the silver, by the iodine vapour. If, on the other hand, a silver plate be charged with iodine vapour, as if for the Daguèrrean process; and if in a dark room there be applied, nearly in contact with it, an engraved plate of copper, steel, or agate, rendered perfectly clean, and free from all adhering gas or moisture, there will be left on the iodized silver a latent impression, capable of being developed by subsequently exposing the plate to mercurial vapour. This image resembles, in all respects, that obtained by the action of light in the process of Daguèrre; and this experiment illustrates very clearly the nature of the action performed by light in that process.

When an iodized plate is exposed in the camera obscura, the light, wherever it falls on the plate, throws the molecules of silver into a state of greater or less agitation. This enables the iodine to penetrate further into the silver, and to leave

the particles, at the immediate surface, less charged with iodine vapour than before,—some of them being reduced nearly to the pure metallic state. Hence, on the subsequent exposure of the plate to the action of mercurial vapour, these disengaged particles condense the mercury; while the portions of the plate which have escaped the action of the light, being already charged with the iodine vapour, cannot absorb that of mercury. It is to this difference that the development of the image is due. The Daguèrrean process is thus merely a particular case of the more general law discovered by Moser; and it was this circumstance which misled that philosopher into the idea, that the images obtained by him were due to latent light, instead of being produced, as they really are, simply by the absorption of gases or vapours.

Beyond furnishing this satisfactory explanation of the action of light in the Daguèrrean process, the phenomena discovered by Moser have no further bearing on the question of the nature of light, seeing they are due to the operation of causes altogether apart from luminous agency. The circumstance, that the action of absorbed gases or vapours explains, in so simple a manner, the formation of the images discovered by Moser, tends to strengthen the idea, that in the production of the images on photographic paper, in the peculiar manner discovered by M. Niepce, atmospheric air performs an important part, and favours the explanation already given of those phenomena.

The mention of these discoveries of Moser suggests a passing notice of his theory of vision. He supposes that in impressing the retina, or rather the choroid coat behind the retina, the light acts exactly as it does on the iodized plate in the Daguèrrean process,—producing an actual, but transitory image of the external object; and that it is this picture on the choroid coat, and not the object itself, which is

immediately perceived by the optic nerve. This idea he supports by many curious facts and ingenious arguments; but all the phenomena may be equally well explained on the supposition of the luminous vibrations acting directly on the choroid coat, and being thence taken up by the fibrils of the optic nerve spread over the retina. Moser's view is favoured by the fact, that there always does exist on the choroid coat an actual image of the object perceived; nor does the rapidity with which the images are formed and obliterated militate against his hypothesis, seeing there are examples of similar rapidity of action in the case of photographic images, which, it is known, may be produced by the almost instantaneous light of an electric spark. The fact already mentioned, however, that the perception of brightness may be produced in perfect darkness by congestion of the optic nerve, without any external object being delineated on the choroid, rather favours the idea, that it is merely the *motion* of the luminous undulations that is transferred to the nerve. For this action is quite analogous to the well-known phenomenon of a singing in the ears, produced by pressure on the nerve of hearing in the absence of all external sound,—an analogy leading to the conclusion, that in both cases mere motion is what is communicated to the nerve, and is in us the cause of perception.

But whichever view be taken, the phenomena are equally reconcileable with the undulatory theory of light. For in ordinary photographic processes the light acts merely as a motive force, which, by exciting vibrations among the molecules of the sensitive surface, either causes them to enter into new combinations, or else predisposes them to do so. Wherefore if the action of the light on the choroid coat be actually photographic, we may conclude that the light merely stimulates into vibration the constituent molecules of the choroid—causing them to enter temporarily into new chemical

combinations,—so giving rise to electro-chemical currents, which being taken up by the fibrils, and thence transmitted along the nerve, like galvanism, excite in it that species of action which causes in us the perception of light and colours. In neither case is it necessary to suppose light to be of the nature of a substance, actually absorbed by the retina.

This last explanation brings to mind what may be termed the *chemical* relations of the ether. Our attention has been hitherto confined to its mechanical constitution,—to the manner in which its luminous waves may originate, and to the laws which govern their movements and relations, after being formed. But, on applying the theory of an universal ether, to explain the phenomena of electricity, magnetism, diamagnetism, and chemical affinity, as well as of light and heat, it appears necessary to suppose the ethereal medium to be composed of two species of particles mechanically alike, but chemically different—that is, having diverse relations to different species of ponderable matter. With respect to the latter it does not appear necessary to suppose that there exist ultimately more than two kinds; at least it is possible to explain the whole chemical phenomena, presented by material bodies, on the supposition of there being only two kinds of ponderable substance which enter into the composition of all heavy bodies, and two kinds of imponderable matter composing the ether. If we call the two kinds of ponderable substance A and B, and the two kinds of ethereal substance X and Y, then their chemical relations may be expressed by saying, that A repels X more powerfully than it does Y, but B repels Y more powerfully than it does X, while A and B attract each other, always tending to pass into absolute contact. It is further needful to suppose that while X and Y have thus different relations to A and B, yet the particles of X repel the particles of Y with the same

degree of intensity as that with which the particles of X repel each other, and the particles of Y repel each other, so that these two exist together in a manner quite analogous to what is observed in the case of two mixed gases. The constitution of the ethereal medium, viewed apart from its relation to ponderable bodies, is thus precisely the same as if it consisted of one species of substance only. It must likewise be assumed, that in the chemical elements each atom in the body consists of one or more molecules of A united to one or more molecules of B in absolute contact, and adhering with a force greater than any that can be brought to disunite them; while the chemical qualities of these elements depend entirely on the proportion between the molecules of A and B in each atom, the tendency being always towards equilibrium.

Hence in the atmosphere of ether, which is supposed to surround each chemical atom, the portion next the A surface of the atom will contain a preponderance of the Y species of ethereal substance; while that portion which is next the B surface of the atom will contain a preponderance of the X species,—these two species X and Y existing in equal proportions in the ethereal medium, and the tendency being to restoration of that state of equality.

These suppositions would explain the polarity of ponderable bodies, as exhibited in the phenomena of electricity, magnetism, and diamagnetism, and also chemical affinity; for when the atoms of a body, containing a preponderance of the A species, are brought near the atoms of a body in which the B species predominates, the tendency to equilibrium would cause them to approximate to each other, and form a compound atom. In so doing, however, they would not pass into absolute contact, else they could never again be separated. Their contact would be prevented by their ethereal atmos-

pheres, which would intermingle at the points of nearest approach,—thus to a certain extent satisfying the tendency to equilibrium subsisting between the two species of ethereal substance, X and Y. The light sometimes evolved when such chemical action takes place between the ponderable atoms may, according to this view, be regarded as a mere indication of the mechanical agitation, generated in the ether by the movements of the ponderable atoms. This curious subject, however, presents too wide a field to admit of more than a passing allusion in this place.

Having thus, in a cursory manner, explained the grounds on which philosophers have been led to prefer the undulatory theory of light to that of emission; having also endeavoured to develop the conceptions which it is needful to form with respect to the universal ether, whose waves are luminous, and having indicated in a very general way the mode in which the wave theory explains the principal phenomena presented by light and colours; having likewise shown that the existence of an universal ether is a supposition, quite as indispensable to the theory of emission as it is to that of undulation, it only remains to point out the bearing of these results on the great question of the permanence of the material universe.

CHAPTER XVII.

"Of old hast thou laid the foundation of the earth: and the heavens are the work of thy hands. They shall perish, but thou shalt endure: yea, all of them shall wax old like a garment; as a vesture shalt thou change them, and they shall be changed: but thou art the same, and thy years shall have no end."—Ps. cii. 25–27.

Notwithstanding the many proofs, furnished by the nice adjustments observed in the planetary system, of a fixed intention on the part of its Designer that it should endure for ever, notwithstanding also that this intention is explicitly set forth in Scripture, yet the idea, that the whole material system is ultimately doomed to inevitable destruction, still clings to the minds of a few philosophers, and is upheld by many divines—the latter founding their argument on the passage above quoted. Of those who contend for the destruction of the entire present material system, one set maintain that it is to be succeeded by another more perfect; while some few form to themselves the extraordinary conceptions that matter is to be ultimately swept away altogether, and that the material universe is to be succeeded by another, consisting of nothing but pure spirits or mere minds. With those who form to themselves this last conception there is no contending, because, to a mind labouring under such an hallucination, arguments could prove of no avail. But the notion that the present material system is to be replaced by another deserves a little more attention. Were this idea confined to the terrestrial system,—were it maintained that this earth, with its appropriate heaven, the atmosphere, is doomed to undergo a change so great that it may be termed a destruction and a renovation, there could

not be any sound objection urged against it. For not only do many phenomena of nature point to such an event, as lying within the bounds of probability, but in the prophecies of Isaiah, chapter lxv. 17, and lxvi. 22, and in 2 Pet. iii. 10–13, there are not obscure intimations that the present terrestrial system is doomed to pass away, and to be succeeded by another more perfect, destined to endure for ever, and from which the taint of moral evil shall be entirely removed.

It is by the light of these prophecies that the passage in the 102d Psalm, above quoted, is to be read. By the word "heavens," as used in all those passages, we are to understand merely the earth's atmosphere, not the planetary or starry heavens. By this simple restriction the divine word is brought into harmony with itself; and the above passages are easily reconciled with the divine declaration that the ordinances of the sun, moon, and stars are intended by their Framer to endure for ever.

This disposes of the argument of the divines deduced from Scripture. But there remains the more formidable objection of natural philosophers, who endeavour to establish from physical phenomena, that the material universe contains within itself a necessary element of destruction,—consequently, that although it may endure for many millions of years, it must ultimately come to an end, or at least pass into such a rickety condition as to stand in need of a thorough repair. If it could be clearly shown that there are natural phenomena, which of necessity involve the conclusion that the material universe has in it an inherent self-destroying element, then we must admit the force of the argument thence deduced, and regard the declarations of Scripture and the evidences furnished by the mechanical adjustments of the planetary system, that its great Designer

intended its arrangements to be permanent, as counting for nothing. We must hold these as evidences that the Deity designed the material system to last a very long time indeed, but certainly not for ever.

On this interesting point the theories of light have an important bearing. Indeed, it may be affirmed that the whole question is involved in the view adopted, with respect to the nature of light, and of the part performed by the ether in the great system of the universe. Those few philosophers, who still cling to the theory of emission, must of necessity adopt the conclusion that the present system of the material universe is doomed to come to an end. For if light consists of emitted particles, the sun, and all the other centres of illumination in the universe, must be in a continual state of dissipation, and a certain, however remote, period must arrive when they shall become wholly exhausted.

If light be produced by the waves of an elastic ether, again, such an ultimate exhaustion ceases to be a matter of necessity. For, seeing that according to this theory nothing is either generated or expended in the production of luminous phenomena, excepting mere motion, it is conceivable that mere motion may be generated without limit, either as to quantity or time. Deferring for the present the consideration of this particular point, it is necessary to dispose of another difficulty which presents itself, arising out of the mere existence of such a medium as the elastic ether, which has been shown to be an assumption necessary to both the theories of light, and especially to the theory of waves.

It is contended by some philosophers that the assumed existence of such an elastic medium is, equally with the theory of emission, subversive of the idea of the material universe being designed to be permanent. It is alleged that if there be an ethereal medium, it must, however fine and

subtle, possess, in common with all other matter, the property of impenetrability—consequently of resistance. It must, therefore, to a certain extent, oppose the motion, through it, of the planetary bodies; and however minute that resistance may be, it must operate in the course of ages, and must gradually reduce the orbit of each planet until it ultimately fall into the sun. Nay, it must cause all the bodies in the universe, by a continual approach to their common centre of gravity, finally to lapse into one.

Some of the supporters of the undulatory theory have too hastily admitted the force of this objection, and even laid hold of it in order to establish their views of the nature of light. "Granted," they say; "the ether must resist the motion of the bodies passing through it; and if we can show evidence of such resistance, it will be an irrefragable proof of the existence of such an ethereal medium. Now, there is Encké's comet; it exhibits the very phenomenon that might be anticipated—a gradual diminution of its orbit. This must be caused by some resistance with which it meets in its progress round the sun; there must therefore be an ethereal medium which is the cause of that resistance."

Were the force of this evidence to be admitted, it would doubtless end all dispute. We must needs believe in the existence of the ether, we must needs believe that it resists the motion of the planetary bodies, and that, so far from being that benign agent which we are wont to regard it—a medium for the diffusion of light and joy—it is a very Abaddon, an instrument of destruction which will ultimately effect the utter ruin of this fair universe. Encké's comet, however, is not an unimpeachable witness in this arraignment of the ether. The planets give a contrary testimony. So far back as the history of astronomy extends, the evidence is clear that there has been no diminution either in the

velocity of the earth's rotation on its axis, or in the size of its orbit; while, as respects the latter, it has been proved to be a clear result of the law of gravity, and a necessary element in the provisions made for the stability of the system, that the *mean* distance of the planets from the sun, and their *mean* motion, should not be subject to any permanent change —an effect secured by the distribution of the masses.

True, the history of astronomy is but a small part of that of our planet; still, a retarding force, whose effects have become so manifest during the short period that Encké's comet has been submitted to observation, ought to have become appreciable in some small degree, in the case of the earth, during so many thousands of years.

To understand this subject more thoroughly, it is needful to keep in view that a body like the earth, in passing through the ether, does not progress in the manner of a ship through the sea, or of a balloon through the air. In those cases there is a displacement of the fluid, exactly corresponding to the entire bulk of the moving mass. Were such the manner of the earth's motion through the ether, that fluid would sustain a large disturbance, which would be in opposite directions, in the opposite portions of the earth's orbit; and so great an opposite disturbance would have an appreciable effect on the light of the fixed stars. The absence of all such effect, then, shows that this cannot be the manner of the earth's progression. A nearer approximation is exhibited by the manner in which a cloud passes through the air; but the analogy is still imperfect, for in this case the cloud is carried forward by a current in the atmosphere; the moving force is in the air, not in the cloud, which is quite passive. In the case of the earth, again, the ponderable matter is not borne along by a current in the ether, but the moving force is in the ponderable matter itself.

Here it is necessary to bear in mind, that of the mass of the earth, as of all heavy bodies, only a portion consists of ponderable substance; the larger portion of the bulk is made up of pores, which, if there be an ether at all, must be filled with that medium. Hence we must conceive of the earth as consisting of ponderable molecules floating in the ether, altogether apart from each other—their mutual distances, though small in themselves, being large in porportion to the size of the molecules. For, as formerly pointed out, it is an intuitive perception of the human mind, that where there is force there must be being. Weight cannot be a property of nothing, but must be an attractive force exerted by some being, having a local existence in space and limited in its presence. Were it otherwise, we should not have the force of gravity diminishing as the square of the distance from a central point; for if the being were everywhere equally present, it would exert its attractive force equally everywhere; but the existence of a central point, where that force is greatest, shows that such central point must be the seat of the limited presence of the being. Hence, the beings, which exert the force of gravity, having a limited presence, must have boundaries and a definite size, however minute that size may be. It is impossible therefore for the human mind rightly to conceive of a ponderable body, otherwise than as composed of molecules having a definite size and weight, but exerting their attractive force at an indefinite distance from their immediate centre of position.

Thus each ponderable molecule in the earth exists in the ether, and moves through it as an independent body; and hence each atom is in itself as it were a counterpart of the entire planet. In like manner the motions which every molecule performs, are counterparts of the planetary motions. In fact every atom of which the earth is composed, except that line of molecules which coincides with its axis, must perform

a planetary motion exactly resembling that of the moon—differing from it principally as respects its period; for whereas the moon takes a month to perform a revolution round the earth, every ponderable molecule composing the latter body (with the above exception, and apart from local disturbance), performs a revolution round the axis of the globe every twenty-four hours; while it simultaneously moves forward in space in the earth's orbit, exactly as the moon accompanies the earth in its revolution round the sun. Thus each molecule of the globe advances along the earth's orbit with precisely the same sort of gyratory or spiral motion, as that with which the moon progresses in the same direction. Nor does the analogy end here. The moon, besides moving round both the earth and the sun, whirls on her own axis, and each particle of the earth is affected by a somewhat similar movement, namely with the gyration or individual orbitual motion, which it possesses as a consequence of the earth's temperature. Again as the moon accompanies the earth in its orbit round the sun, even so each molecule of the earth accompanies the sun in its orbit round the centre of gravity of the milky way.

Of this species of gyratory motion, we have an analogous example in the case of the cyclone or whirling tempest, which has recently been made the subject of minute investigation. In this case the molecules of air, carrying with them those of vesicular watery vapour and of dust which are floating in the atmosphere, have both a whirling and progressive motion. The whole molecules are moving round a centre, while that centre is itself performing a curvilinear motion. Indeed it has been recently shown that all winds, even the faintest breezes, partake of this character; an evidence of which is afforded in the curling of smoke or steam, which is just a visible manifestation of this gyratory motion affecting the molecules of carbon and of vesicular watery vapour.

But let us confine our attention to what may be called the planetary motion of the molecules composing the earth, and to the manner in which that motion may be affected by the ether. Here three possibilities present themselves. First, the molecules may help each other in their progress through the ether; second, they may hinder each other's progress; or third, they may neither help nor hinder one another.

If the ether oppose some resistance to the progress of the molecules, and if they help each other in overcoming that resistance, then dense bodies will be less affected by that resistance than rare bodies, and the denser parts of bodies than their rarer parts; the resistance being in some inverse porportion to the number of molecules moving together through the ether. This idea would furnish an adequate reason why (supposing the ether to oppose a resistance to the progress of ponderable bodies,) Encké's comet, whose matter is exceedingly rare, should suffer more from that resistance then the denser mass of the earth. But unfortunately for this explanation, it involves a conclusion which is fatal to it; for if the rarer parts of bodies be more resisted than the denser, then the outermost portions of our atmosphere being many thousand times rarer than the matter at the surface of the earth, and equally as rare, if not rarer than the matter of Encké's comet, the molecules of air in those outermost strata must be equally resisted with those of that comet, and greatly more resisted than the molecules at the earth's surface. Further, molecules in the equatorial parts of the atmosphere perform a much longer and more rapid journey through the ether than those situated near the poles; consequently the former must be greatly more retarded than the latter. From the continued operation of these two causes, it would happen that the earth's atmosphere would be constantly changing in form and shrinking in volume. The orbits in which the

outer molecules move round the earth, would be continually diminishing like the orbit of Encké's comet; and as the equatorial parts would be thus affected more than the polar parts, the atmosphere would be continually becoming less and less oblate in its figure.

We search in vain, however, for any evidences of such changes; whereas such a diminution in volume ought to be easily traceable; because it has been shown by Laplace that it would be attended by an acceleration of the earth's rotation —an effect of which there is no trace during the long period that astronomical observations have been continued. Hence we see that the supposition that the molecules help each other's progress through the ether, avails nothing in explaining the phenomenon of Encké's comet, and must be rejected as contrary to the evidence.

Suppose now that the molecules hinder each other's progress through the ether. In this case the resistance would be in some direct proportion to the number of the molecules advancing together; consequently denser bodies would be more retarded than rarer, and the denser parts of bodies more than the rarer parts. In this case the earth should exhibit stronger evidences of retardation than Encké's comet, so that on this supposition also the idea of resistance is contradicted by the phenomena.

In like manner, if the molecules neither help nor hinder each other in their progress, then the resistance should be the same in large bodies as in small, in dense bodies as in rare, and the earth should exhibit the same amount of diminution in its orbit and acceleration in its speed, as are observed in Encké's comet, whereas it exhibits none.

Upon this topic some misapprehension appears to exist in the minds of even eminent philosophers, who have been misled by a false analogy. They argue that because a cloud of

dust, or a wreath of smoke, is less able to force its way through the air than a musket ball, therefore such a rare body as Encké's comet must be less capable of making its way through the ether, than a dense mass like the earth. This analogy would be correct, only on the supposition that bodies progress through the ether as they do through the air, by displacing a portion of the fluid corresponding to their volume, but independent of their weight; whereas it has been shown that this cannot be true; but that each atom composing a body, however dense or rare, must thread its own independent way through the ether. A comet would therefore be arrested more than a planet, only on the supposition that the individual atoms of which it is composed, are *specifically* lighter, but not from the atoms being placed at greater mutual distances, so as to reduce the specific gravity of the mass. On the contrary, the further apart the atoms are, the more easily should they thread their individual way through the medium. Now although we may determine the relative weight of the individual atoms, we cannot ascertain their size; and it would therefore be an extravagant supposition to imagine that the atoms composing Encké's comet, have each individually a smaller weight compared with their size, than have the atoms composing the planets. All analogy leads to the inference, that the great rarity of the comet is due to the largeness of the distances between its component atoms —not to any specific lightness in the atoms themselves.

To whatever cause then the diminution in the orbit of Encké's comet be due, it appears highly improbable that it is to the resistance of the ethereal medium; and it is accordingly to be expected that future researches will discover a more rational explanation of this phenomenon. All the perturbations of the planetary bodies have not yet been fully examined and explained. Fresh discoveries are continually

being made of small planets, which have previously eluded the scrutiny of observers; and their disturbing force has yet to be determined. The perturbations due to only one cause —that of the mutual gravitation of the planets—have not yet been exhausted; while the possible disturbing effects of another cause, that of the electricity and magnetism, now known to be so largely developed in the earth, and probably in the other planets, constitute a field of research as yet unexplored. The comets being composed of gaseous matter, are likely to be highly susceptible of these latter influences; for it has been shown by Faraday, that the gases are either magnetic or diamagnetic—oxygen gas in particular being sensibly magnetic. To one or other of the causes above indicated, may the observed diminution of the orbit of Encké's comet be due. It may be only one of the phases of a change, which, in the course of time, will begin to manifest itself in an opposite direction; and so long as this possibility remains, so long must we refrain from attributing the phenomenon to the resistance of the ether.

This view is strengthened by what occurred in a case almost perfectly analogous. By a comparison of ancient with modern observations, it was ascertained that the moon now performs her mean revolution round the earth in a shorter time than she did in former ages; consequently, that her orbit has been very slowly, yet perceptibly diminishing during the period embraced in astronomical history. For some time after this discovery was made, it was regarded as evidence that the moon was retarded in her course by a resisting medium; consequently, that in the end she must fall to the earth. A more minute investigation of the distributing forces exerted by the other planets, however, led to the discovery of the true cause of this phenomenon, and showed that no such untoward issue is to be apprehended. It was proved

that by the action of the other planets, the form of the earth's orbit is very slowly but continuously undergoing change—its elliptical form alternately decreasing and increasing in eccentricity, and that by this change the moon's motion in her orbit is alternately quickened and retarded; these changes requiring for their accomplishment a period of millions of years. Now in like manner it may eventually be found, that the effect of the perturbing influence of the various planets upon Encké's comet is such, that it brings it alternately more or less within the influence of the sun's gravitation; so causing an alternate diminution and increase in its orbit; the diminution at present observed, being only one of the phases of this alternation, and not due to the resistance of the ether.

An important step towards such an explanation, has apparently been made but a short time ago. At the meeting of the British Association, held at Dublin in 1857, it was pointed out by Mr. Penny, that among several other perturbations, arising from the product of the disturbing forces of two or more planets, not the least remarkable is one affecting Encké's comet, due to the disturbing forces of Jupiter and Saturn. The mean motion of the comet is very nearly equal to four times the mean motion of Jupiter, less that of Saturn, a relation giving rise to two considerable perturbations, one of which appears to account for a large portion of the observed diminution of the comet's orbit, if not for the whole. There will also, from a similar cause, be a like perturbation in the motions of all the comets of short period.

The probability that this will eventually be found to be the true explanation of this phenomenon, is enhanced by the observations and calculations which have been made with respect to the periods of the celebrated comet of Halley. The following are the periods calculated from the recorded observations of that comet:—

From 1378 to 1456	77·58 years.
From 1456 to 1531	75·21 years.
From 1531 to 1607	76·15 years.
From 1607 to 1682	74·91 years.
From 1682 to 1759	76·49 years.
From 1759 to 1853	76·68 years.

From an inspection of these figures, it is evident that, from its first recorded appearance in 1378 down to 1682, the period of revolution was in a tolerably regular course of diminution—so confirming the supposition that the comet was impeded by a resisting medium; but from 1682 to 1853, an opposite effect has prevailed, and the period has been gradually increasing. There is thus raised a strong presumption, that the period of Encké's comet will ultimately be found to undergo a similar alternate acceleration and retardation, which will become manifest in the course of time.

CHAPTER XVIII.

"Thou hast established the earth and it abideth."—Ps. cxix. 90.

The evidence supposed to be afforded by the observed retardation of Encké's comet, in favour of the idea, that the universal ether, by reason of its resistance to the progression of ponderable bodies, must ultimately cause the destruction of the present system of the material universe, having been considered and shown to be of little weight, it remains to examine the question in another aspect. Granting that the retardation of Encké's comet may be otherwise explained, still the objection subsists,—must not the ether, if it exist at all, oppose a certain amount of resistance to the motion through it of ponderable molecules; and does not the absence of all evidence of resistance merely prove, that there can be no such medium as the ether? Now it is quite true, that if a ponderable molecule move through an elastic ether, it must continually displace a portion of the medium, equal to its own bulk, and in so doing it must impart motion to the ethereal particles, and lose an equivalent amount of its own progressive force, and, however minute the quantity thus lost may be, it must, if there be no compensation, accumulate in course of time. This, however, is the case only of a particle moving through a *still* ether, imparting motion to the medium, and receiving none in return; but this is not the case presented before us. According to the undulatory theory, the ponderable molecules are continually *receiving* motion from the ether, a motion whose amount is measured by the temperature of ponderable bodies. It is, therefore, quite possible that the motion thus communicated by the

ether to the ponderable molecules may be such, both in amount and direction, as to compensate for the loss of motion which these molecules sustain, in forcing their way through the ethereal medinm.

Viewing light as mere motion, it is obvious, that there are continual fresh supplies of motive force coming from the sun. Now what becomes of all this motive force? A portion of it is propagated *ad infinitum* through the boundless ether; but whenever in its course it is met by ponderable matter, it is there arrested in its progress. One portion is reflected back into the ether, to pursue its journey in a new direction, but the larger portion is employed in imparting motion to the ponderable molecules.

Now the amount of motive force, thus continually coming from the sun, is not small. When a large quantity of it is concentrated and brought to bear on a small surface, its effects on ponderable bodies are very powerful—producing in their molecules, an amount of agitation which rends asunder the strongest ties of cohesion, and dissipates the most solid of substances into vapour. It has been estimated that the motive force expended in raising one pound of water 1° Fahr. of temperature, in a second of time, would, if applied as an impulse in one direction, lift 772 pounds one foot in a second; and the same quantity of heat would raise one pound of air about 4° Fahr.; so that the communication of 1° Fahr. to one pound of air is equivalent to raising 193 pounds one foot high in a second. It has further been calculated, that the mechanical value of the motive force of the solar undulations, received every second on a square foot of surface, above the earth's atmosphere, is equivalent to that of a machine, that would lift 83 pounds one foot in a second; consequently it would be sufficient to impart about 1° of temperature to 0·43 pounds of air every second. There being

about 2160 pounds of air on every square foot of the earth's surface, the solar undulations (were their whole energy expended in raising the temperature of the air) would accordingly require about eighty minutes to raise it to 1° Fahr. of temperature; so that every twelve hours the quantity of heat imparted to the air would be 9°, if the solar undulations were wholly exhausted in the effort. But as only about half their motive energy is expended in passing through the air, the quantity of heat which they directly impart to the atmosphere every twelve hours, cannot be estimated at more than between 4° and 5°.

But if the ponderable molecules be thus perpetually receiving motive force from the sun, it is plain that their motion would be continually becoming greater and greater, unless, in some way or other, they lost exactly as much as they gained. If the quantity of motion, therefore, in any ponderable molecule, attain a fixed average amount, it is obvious that the loss and gain of motion must be exactly equivalent to each other.

Now this is precisely the case of the earth's atmosphere. It has already been pointed out, that were the earth's atmosphere to diminish in volume, the rotation of the globe would be quickened; and if it increased in volume, the rotation would become slower. But as the average length of the day and night, over the whole globe has remained constant, during the entire period embraced in the history of astronomy, it is obvious that the volume of the atmosphere, consequently its average temperature, must have remained constant all that time. For the same reason, it may be concluded that the temperature of the earth is also a constant quantity. It having been ascertained that the length of the sidereal day has not altered one ten-millionth part in 2500 years, it follows that the radius of the earth

cannot have altered one twenty-millionth part of its length in that time—consequently the temperature of the globe cannot have altered to the extent sufficient to produce so minute a change. A variation of temperature, to the amount of 1° Fahr. would probably alter the earth's radius about one two-hundred-thousandth of its length; so that the temperature cannot have changed by one hundredth of a degree in 2500 years.

This constancy of the earth's temperature may be also deduced from another consideration. It has been pointed out by Arago that for the date to ripen, the mean temperature must exceed 70° Fahr. while the vine cannot be cultivated with success, if the mean temperature surpass 72°. Hence, if in any place both dates and grapes attain perfection, its mean temperature must lie between 70° and 72°. Now we learn from the books of Moses, that in his time both dates and grapes grew luxuriantly in the valleys of Palestine, the mean temperature of which, at that early epoch, is thus determined; and it is found to be the same at the present time.

It must be kept in view, however, that only one half of the globe is exposed to the influence of the sun at a time; so that there is always a considerable difference of temperature, between the two halves. Observations are wanting, to enable us to determine this difference, with any degree of precision; but in Dove's tables of temperature, there is a selection made of seven places, in various quarters of the globe, in which the mean differences of temperature of the twelve warmest and the twelve coldest hours are given. The general average of all these is about 5°·4, but four of the places are near the sea and present an average difference of only 4°·6, while the average given by the three inland places is 6°·2. Hence, taking the ratio of the sea to the land as about three-fourths of the terraqueous surface, we obtain a

general average for the globe of 5°, as the difference of temperature between the twelve warmest and the twelve coldest hours. This brings the estimated loss to within half a degree of the estimated gain of 4°·5 by the direct action of the solar rays on the atmosphere; but the air derives a certain amount of heat by reflection and radiation from the earth, which will account for this difference of half a degree; so that 5° may be fairly taken as the daily average of loss sustained, and gain acquired, by the atmosphere from the operation of the constant forces which act upon it. It thus appears that one half of the earth's atmosphere loses about 5° of temperature every night, and the greater proportion of this loss falls on the quadrant between midnight and sunrise. Moreover, as air loses about one four-hundred-and-eightieth part of its volume, for each degree of temperature, it follows that the atmosphere on the dark side of the globe is nearly one ninety-sixth part denser than on the illuminated side.

It is thus evident that the molecules, composing the atmosphere, lose a considerable amount of their motive force through the night; and the question is—what becomes of it? It is not communicated to the molecules of the earth and sea; for these generally possess a higher temperature than the superincumbent air. We must therefore look to the ether as the cause of this abstraction of force. The ponderable molecules may lose their motion by imparting it to the ether, in one of two ways—either by exciting invisible undulations in that medium, or simply by displacing its particles in their progression through it; or again, both of these causes of loss of motion may subsist together. Now we can never obtain any positive proof, that the ponderable molecules of the air impart invisible undulations to the still ether on the dark side of our planet. The direct evidence is rather negative, for there are scarcely any traceable invisible

undulations transmitted to us by the moon. It is merely by inference that we conclude, that the ponderable molecules must communicate invisible undulations to the ether. On the other hand it is obvious, that the ponderable molecules must impart motion to the ethereal particles, by displacing them in their passage through the ether, and that they lose part of their own proper progressive motion in so doing, is manifest from the result.

The loss of five degrees of heat is only the measure of the diminution in the amount of gyratory motion, which the ponderable molecules of the air perform in virtue of their temperature. But as the atmosphere must at the same time lose about one ninety-sixth of its height on the colder side, each of its molecules must perform a shorter journey in its progress round the earth's axis, during the night, than during the day. Yet, each molecule takes as long to complete the shorter, as to accomplish the longer journey. It is therefore plain, that it has lost progressive motion, and that this result is exactly such as ought to follow, from the resistance due to the displacement of the ethereal particles.

We see, however, that this loss of motive energy, which is considerable, and which, were it not compensated, would rapidly accumulate, is regularly made up from day to day, by virtue of the motive force received from the sun; for, in consequence of that acquisition, each molecule of the atmosphere, on the sunny side of the globe, performs in twelve hours a longer journey than does each molecule on the dark side.

As in consequence of the difference between the day and night temperature, the average height of the atmosphere on the sunny side of the globe exceeds by about one ninety-sixth part its average height on the dark side, the air must always be specifically heavier on the dark than on the light side of

the globe. This difference of density will also extend, in a small degree, to the outermost layers of the terraqueous surface, but it will penetrate to only a minute depth. Now this excess of specific gravity, on the dark side of the globe, will cause the centre of gravity to be always removed to a small distance further from the sun, than the true centre of the earth's figure, including, of course, in that figure the outer surface of the atmosphere. Moreover, as the greatest heat is after noontide, and the greatest cold after midnight, this excess of specific gravity will be greater on one half of the dark side than on the other, consequently the centre of gravity will always be slightly removed to one side of the true centre of the earth's figure. To a person regarding our globe from the sun then, it would manifest a slight amount of top-heaviness, the upper half of its figure being a little heavier than the lower, this excess of weight, moreover, being more to one side than the other. Now a body in this condition must always have a tendency to topple over and turn its heavier side to the sun; and as the heavier side, in turn, becomes the lighter, this tendency to toppling would become a tendency to rotation. Hence the inequality of temperature on the two sides of the globe, must to a certain small extent favour the rotation of the earth on its axis. In like manner the motion of the earth in its orbit being in the same direction as the rotation on its axis, and the position of the heavier half of the dark side of the globe being such as to remove the centre of gravity slightly to the rearward of the centre of the earth's figure, there will thus arise a constant minute tendency to advancement in the direction of the earth's orbitual motion. These small tendencies in favour of the earth's rotation and progression, caused by the solar heat, may accordingly be the exhibition on the mass of that compensating force, which is exerted on each molecule, and

which produces an exact counteraction to the resistance experienced by the molecule in forcing its way through the still ether.

The general conclusion, however, does not depend on the accuracy of this view. The broad fact remains, whether we be able to explain the mode of operation or not. It is clear that the molecules of the earth's atmosphere do, in the twelve hours, perform a shorter journey on the dark side than they accomplish on the light side of the globe; consequently, they do experience retardation on the one side, and acceleration on the other. Hence it is only when not agitated by undulations that the ether deprives the ponderable molecules of part of their progressive motion; and this loss is restored to them in passing through a portion of the ether, which is in a state of undulation—the loss and gain exactly counterbalancing each other. Thus neither force can accumulate or produce any permanent effects which might derange the general system of the universe.

CHAPTER XIX.

"With thee is the fountain of life."—Ps. xxxvi. 9.

The propositions that light is caused by the waves of an universal elastic ether, and that this medium opposes a certain amount of resistance to the progression of heavy bodies, have been shown to be admissible without involving, as a necessary consequence, the idea that this ethereal resistance must ultimately destroy the present mechanism of the universe.

Evidence has been adduced tending to prove that, from the operation of this resistance, there is sustained by the ponderable masses no uncompensated loss of motion. What really subsists is a continuous interchange of motion between the molecules of heavy bodies and the particles of the ether.

When a planet interrupts the tide of undulation coming from the sun, it causes stillness to prevail throughout an indefinite column of the ethereal expanse, which would otherwise be agitated by the solar waves. In other words, the planet projects a shadow far into the infinite ether. There is thus sustained by the ethereal medium a loss of motion, which, save for the intervention of the planet, it would continuously obtain. But the motion thus apparently lost is not really extinguished, it is all imparted to the ponderable molecules of the planet; and this accession of motive energy would accumulate, were it not given back to the ether in another shape. It is required to give to the ethereal particles that species and amount of motion, which is needful to enable them to make way for the ponderable molecules passing through their intervals. This motion manifests itself, on the

great scale, in the contractions and expansions which the ethereal medium undergoes, as the planet passes through it. The quantity of ether present in the space, occupied at any instant by the planet, is the same, whether the planet be present or absent, the ether merely becoming more compressed by the presence of the planet. But this alternate compression and dilatation of the medium cannot take place, without the absorption of motive energy; and this energy is derived from the ponderable molecules, which, in their turn, receive it from the undulations of the ether.

It thus appears that, while it may be freely admitted that the ether must oppose a certain amount of resistance to the passage through it of the ponderable molecules of the planetary bodies, this admission by no means involves, as a consequence, the conclusion that the planetary masses themselves must, in passing through the ether, sustain a loss of motive energy and progressive motion, which would result in their ultimately falling into the sun. Hence the argument against the permanence of the material system, based on the supposed retarding influence of the ether, cannot be maintained.

Seeing then that the mere assumption of the existence of the ether is not inconsistent with the permanence of the present arrangements of the material universe, it only now remains to be considered, how far the question of that permanence is affected by the theory that light consists of mere undulations in this ether, and not of material particles emitted from luminous bodies, and propagating before them ethereal waves, which modify the rate and direction of their progress.

The question of the permanence of the material universe thus resolves itself into this other, Is it possible for motion to be generated without limit? Did light consist of emitted particles, the permanence of the material system could not be maintained, unless there were a continuous fresh creation

of matter; because the matter of the sun and fixed stars would be in a continual state of dissipation. But a similar difficulty arises on the assumption of light being mere motion, because the motion, generated in the sun and fixed stars, is in like manner in a continuous state of dissipation; and without some provision being made for constant renewal, the forces, by which the motion is generated, would ultimately become exhausted. There is, however, this great difference between the two cases. We have no example whatever of the absolute creation of even a single atom of matter; whereas we have before our eyes constant examples of the continuous multiplication of beings capable of exciting motion, namely, those beings possessed of the principle of life. The origin of the living principle, in any organized being, is a question beyond the limits of the human understanding. We can refer it only to the continual putting forth of the divine energy—adopting the words of the Psalmist, "Thou sendest forth thy Spirit, they are created." No sane mind can deny to the Deity the power of continuously multiplying living beings without limit, or ignore the fact that we have examples of such continuous multiplication to which we can assign no other cause whatever, than the action of that divine Mind which is the source of all life. Now, if it be undeniable that life is thus in a continuous state of generation, it must be equally undeniable that motion is in a continuous state of generation, because every living being is endowed with the capacity of producing motion of one sort or another.

It is well known that some living creatures are endowed with the power of directly generating those undulations in the ether, which produce in us the perception of brightness—the most remarkable examples being the minute organisms which cause the phosphorescence of the ocean. But it is by

no means necessary to imagine that light, where it is produced continuously without diminution, originates *directly* with the living principle. If the light be supposed to originate merely with the mutual action of inorganic bodies, in any manner whatever, these bodies, by such mutual action, ultimately pass into a condition in which their power of affecting each other ceases, and the motion comes to an end. But then, by the intervention of the living principle, the inorganic bodies may be again brought into such a condition, as to enable them to act on each other as before, and so to produce a fresh supply of motion and light.

To illustrate this point by an example. Let definite quantities of carbon and oxygen gas be carefully weighed, and then allowed to unite by combustion. This mutual action will generate a certain definite quantity of motion, a large portion of which will assume the form of luminous waves. But, on the union between the oxygen and the carbon being completely formed, the action will cease, and the result will be an equivalent quantity of carbonic acid gas. In this condition the constituent materials are reduced to a state of repose. If there be now introduced into the carbonic acid gas a living plant, this organism will by degrees decompose the gas, appropriating the carbon and setting free the oxygen. These two constituents are thus brought back into such a condition, that they be made again to exert their mutual action, and, by reuniting, to generate a fresh supply of motion and light.

It may be objected to this view, that the motive energy of the sunbeams is indispensable to enable the plant to effect this decomposition. But the offices performed by the sunbeams and the plant are quite distinct. The sunbeams predispose the compound molecules of the carbonic acid gas to decomposition. They excite vibrations, within each molecule, be-

tween the atoms of carbon and oxygen, of which it is composed. The plant seizes the moment of greatest separation, caused by these vibrations, to effect the decomposition; it appropriates the carbon and frees the oxygen. Thus the predisposing vibrations are the only true representatives, or equivalents, of the motion communicated by the sunbeams. In the absence of the plant no further effect would ensue.

Hence the plant, or rather the living somewhat which organizes the plant, is the real agent by which the liberation of the carbon is effected, and by which is restored its capacity of re-entering into combination with oxygen, and thereby generating motion anew.

In effecting this change, the living being acts as a prime mover, or ultimate fountain of force. It is the power imparted by the living being which becomes latent in the carbon, and not the motion of the sunbeams; these produce merely the predisposing vibrations. Motion cannot become rest for an indefinite period, and then re-appear as motion. But a living being, possessed of inherent motive energy, and formative or organizing force, may, by virtue of these powers, so alter the electrical condition of the atoms composing a compound molecule, as to restore them to the elementary state, and thus enable them again to exert chemical affinity, and generate the motion attendant on chemical combination, which is merely a variety of electrical discharge.

Whatever then may be the immediate origin of the light of the sun and fixed stars, a point upon which we can never obtain any certain knowledge, it is quite conceivable that the materials, whose mutual action generates the motion, manifested in the luminous undulations, after passing into that state of repose, which of necessity ensues, may be again restored to a condition, which renders them capable of repeating this action, and so generating fresh luminous waves.

Analogy further warrants the conclusion, that this restoration may possibly be accomplished, by means of organic beings which are in course of perpetual generation.

The possibility of the existence of organic beings, in the sun and fixed stars again, depends on the constitution of those luminaries. If they be solid or liquid masses, in a state of glowing incandescence, any idea of this kind would be preposterous. Such, however, does not appear to be the most probable constitution of those luminous orbs. It has already been shown, that the light of the sun is most likely derived from a gaseous envelope, surrounding his more compact mass, and at a considerable distance from it; while, intervening between these two, there is a deep layer of very dense vapours, preventing the glare of the luminous region from reaching the compact surface, which is thus comparatively dark. As regards the question of temperature again, that of the compact surface will depend on the nature of the intervening atmosphere of vapour or gas, subsisting between it and the luminous envelope. The constitution of this atmosphere may be such, as to render the amount both of light and heat at the compact surface so moderate, as to be in the best manner adapted to promote the rapid propagation and development of living organisms. Arago, adopting this view of the constitution of the sun, expressed his conviction, that there is nothing at all improbable in the supposition of the sun and fixed stars being the abodes of countless organic beings.

The question of the permanence of the material universe is thus seen to depend on the possibility of there being, in the sun and fixed stars, a continuous and never ending efflux of the living principle from the fountain of life and being. This is quite a different idea from that of the continuous creation of material atoms. Of such a creation we have no experience; but the continuous emanation of the living principle animat-

ing a countless variety of organic forms, both animal and vegetable, is a phenomenon which we witness every day. To account then for the fact of the light of the sun and fixed stars, or of the motion constituting that light, being supplied continuously and without diminution for millions upon millions of years, we have only to suppose, that it in some way or other depends, either directly or remotely, on a continuous emanation of life, or organizing force, in those orbs. And if such be the source, whence the motion is derived, it must obviously be incapable of exhaustion; for its perennial fountain is no other than the vital energy of the ever-living God.

According to this view, the material universe is not a perfect automaton, which, being once set a going, will continue its various movements to all eternity. Neither is it an imperfect automaton, containing within itself a necessary element of decay. It is more like a perfect machine continuously kept in motion by the living hand of its contriver. The permanence of the present arrangements thus depends entirely on the will and intention of Him who formed them; but it is permitted to us to judge of what his will and intentions are, by a careful study of these arrangements themselves. Now the evidence furnished by these all tends to one conclusion. It shows that in the planning of the disposition and movements of the heavenly bodies, the Creator had in his mind's eye the securing, not only of their perfect adaptation to their several purposes, but also their endurance for ever and ever.

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